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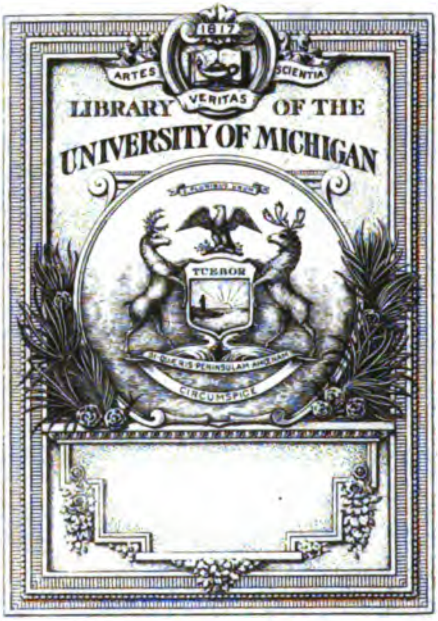

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A TREATISE OF MECHANICS,

THEORETICAL, PRACTICAL, AND *DESCRIPTIVE.*

BY

OLINTHUS GREGORY,

OF THE ROYAL MILITARY ACADEMY, WOOLWICH.

VOL. II.

CONTAINING

Remarks on the Nature, Construction, and Simplification of Machinery, on Friction, Rigidity of Cords, First Movers, &c.

AND

Descriptions of many curious and useful Machines.

> ——Talem intelligo Philosophiam naturalem, quæ non abeat in fumos speculationum subtilium, aut sublimium; sed que efficaciter operetur, ad sublevandi vitæ humanæ incommoda. Bacon. *De Aug. Sci.*

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MECHANICS

Remarks on Machinery in General.

1. MECHANICS, according to the original import of the word, treats of the energy of Machines: and theſe machines are nothing more than *organa*, or tools, interpoſed between the workman or natural agent and the taſk to be accompliſhed, in order to render that work capable of being performed, which under the limits and circumſtances propoſed would have been difficult, if not impoſſible, without the intervention of ſome of theſe contrivances.

Machines are interpoſed, as was remarked (art. 379. vol. I.), chiefly for three reaſons. 1. To accommodate the direction of the moving force, to that of the reſiſtance which is to be overcome. 2. To render a power which has a fixed and certain velocity efficacious in performing work with a different velocity. 3. To enable a natural power, having a certain determinate intenſity, to balance or to overcome another power or obſtacle, whoſe intenſity or reſiſtance is greater. Each of theſe purpoſes may be accompliſhed in different ways: *i. e.* either by machines which have a motion round ſome fixed and ſupported point, as the lever, the pulley, and the wheel and axle; or by thoſe which, inſtead of being ſupported by a fixed *point*, about which they move, furniſh to the reſiſtance, or body to be moved, a ſolid path, along which it is impelled, as the inclined plane, the wedge, and the ſcrew. Compound machines are peculiar combinations of theſe ſix, of which we have treated individually in the firſt book of our firſt volume: ſome remarks likewiſe upon their combination have been given in Book I. Chap. IV. art. 161. and Book II. Chap. VI. And we have treated of the ſtrength of the materials of which machines may be compoſed, in Book I. Chap. V. Such farther obſervations as appear neceſſary to complete a theoretical and practical knowledge of Machinery in general, previous to our alphabetical deſcription of particular machines, will now be preſented to the ſtudent.

2. Simplicity in the conſtruction of machines cannot be too warmly recommended to the young engineer: for multiplicity of parts and of motions increaſes the expence of erection, augments the friction, and multiplies the danger of failure by the bending or by the inaccurate adjuſtment of the parts. In conſequence of the effects of friction (of which we ſhall ſpeak more fully, art. 24, &c.), it is well known to all engaged in the practice of mechanics, that by no combination of wheels, or levers, or other powers, can one weight be made to move another with a greater or even an equal momentum: and by the multiplication of wheels, levers, &c. the effect of the machine, inſtead of being increaſed, is diminiſhed in proportion to the augmented friction of the moving parts. Hence it follows that in practice, effect is loſt by mechanical combination, but gained by ſimplification; and that the moſt perfect machine is that which operates by the feweſt moving parts. In order to contrive a ſimple machine to be theoretically equivalent in power to a complex one, the following rule may be obſerved: Conſtruct the various parts of the ſimpler machine ſo that the velocity of the impelled point (art. 365.) ſhall be to that of the working point, in the ſame ratio as they are in the compound machine; then will the effects of theſe two machines be the ſame, ſo far as depends upon pure theory: but in practice the ſimpler will be the more efficacious, in conſequence of the diminution of friction.

3. For an example, ſuppoſe the compound machine fig. 1. pl. II. were to be propoſed, in order that a more ſimple one might be conſtructed to perform the ſame work. Let CA, the lever to which the power is applied, be 10 feet, DE five feet in diameter, EF = 2 feet, HI = 3 feet, GH = 5 feet, and KL = 1 foot, the latter being the cylinder on which the rope raiſing the weight W folds. Now the diameter of the circle deſcribed by the power at A is 20 feet: and to find the diameter of the circle whoſe circumference is equal to the ſpace paſſed over by W in one revolution of the lever CA, reduce the following fraction, viz. $\frac{DE}{2\,AC} \times \frac{GH}{EF} \times \frac{KL}{HI} = \frac{5}{20} \times \frac{5}{2} \times \frac{1}{3} = \frac{5}{24}$ of 2 AC; conſequently the velocity of the weight is $\frac{5}{24}$ of that of the power. And hence, if upon the vertical axis CM (fig. 2. pl. II.) a wheel be fixed the diameter *k l* of which is equal to $4\frac{1}{6}$ feet (that is, $\frac{5}{24}$ of 2 AC), the weight W will be raiſed the ſame height by the ſimple as by the compound machine, at every revolution of the power A. So that, the ſimple machine ACM*k l*, will be at leaſt equal in effect to the compound one ACMDEFGHIKL, and the wheels DE, EF, GH, HI, and KL, are extraneous, and probably prejudicial.

4. For another example take the following. In the common wheel and axle, the advantage gained is in the ratio of the radius of the winch to that of the barrel: ſo that when it is propoſed to increaſe that advantage, either the handle muſt be lengthened, or the diameter of the axle diminiſhed; neither of which, however, is practicable beyond certain limits, becauſe the handle might be too long for convenient management, or the axle too ſlender to ſupport the load: in ſuch caſes it is uſual to annex another wheel and pinion, or a tackle of pulleys. But the following conſtruction is greatly preferable. In fig. 7. pl. I. the part A of the barrel is larger than the part B, and the rope which paſſes under the pulley C and ſuſtains the weight D is wound upon each in contrary directions. Whenever, therefore, the handle EF is turned, ſo as to gather the rope upon the larger cylinder, it will be given off by the ſmaller: and for every turn of the larger, or its correſpondent portion of rope wound up, there will be given off a portion of rope anſwering to the circumference of the ſmaller. Conſequently, the quantity of unwound rope will be leſs after ſuch a turn, by a portion equal to the difference between the circumferences of the two cylinders; and the weight D will be raiſed through half that ſpace. Whence, ſince the radii of circles are as their circumferences, we may uſe this analogy:

As the radius of the winch,
To half the difference of the radii of the cylinders;
So is the weight,
To the power balancing it.

In fig. 8. is exhibited a ſimple capſtan in which the ſame contrivance is adopted. Here, if the upper barrel A were 17 inches diameter, and the lower B 16 inches, the pulley C being alſo 16 inches diameter; it will be obvious that this ſimple capſtan will be equivalent to an ordinary capſtan of the ſame length of bar EF, and diameter of barrel B, combined with a 16-fold tackle of pulleys; and at the ſame time free from the great loſs by friction and bending of ropes, which would abſorb at leaſt a third of the power of a 16-fold tackle.

One peculiar advantage of this engine is, that the half difference of the radii of A and B may be diminiſhed *ad libitum*, without weakening the cylinder, increaſing the friction, or requiring any rapid curvature of the rope. This windlaſs has likewiſe the peculiar property of holding the weight at any part of its riſe or fall without needing a ratchet wheel and catch. Its only practical diſadvantage, that a great quantity of rope muſt be uſed to produce a moderate change in the poſition of the weight; but the quantity of rope will be much leſs than what is requiſite for an equivalent tackle of pulleys. This ingenious contrivance is generally aſcribed to the celebrated *George Eckhardt;* and he probably invented it without knowing that it had been uſed elſewhere: but we have ſeen a figure, from which our figure 8. is merely a copy, in ſome Chineſe drawings of nearly a century old.

5. The methods of communicating motion from one thing to another, or from one point to another, are almoſt infinitely diverſified: ſo that it will not be expected that they ſhould all be deſcribed here. It is manifeſt that the communication of motion will in different circumſtances be better effected by means of one ſimple machine (or, as they are uſually called, mechanical power), than by another; and much of the ſkill of the engineer conſiſts in chooſing the inſtrument moſt proper for the purpoſe propoſed: and the ſame will be the caſe with regard to more complex machines. In ſome inſtances a ſimple lever, or a ſimple unbent cord, will anſwer better than any combination: in others it may be highly advantageous to uſe a combination of levers acting upon each other, by means of ſo many fulcra; and by theſe the *direction* may be changed at pleaſure: in others, as when motion is communicated to a ſeries of wheels and axles in ſucceſſion, it may be effected by a rope running in grooves round one wheel and the ſucceeding axle; or by what was deſcribed in vol. I. art. 246. under the name of tooth and pinion work: in others again, by a barrel and winch with an endleſs ſcrew, And many other contrivances will readily ſuggeſt themſelves to an ingenious artiſt.

6. But ſuch ſimple methods cannot always be adopted. Thus when it is required *by means of a rotatory motion to produce a reciprocating one*, as the alternate motion of the piſtons of pumps, for example; one of the following contrivances may be uſed. To a vertical ſhaft as AP (fig. 6. pl. II.) fix a large horizontal wheel MOIL, the lower part of which is indented in waves MSO, OQI, &c. of which the conſtituent arches are either circular or parabolic. On a convenient point D of an upright poſt as a centre of motion, let a lever EDC move; one end of it carrying the moveable vertical wheel CR, in ſize properly adjuſted to the waves of the horizontal wheel; the other EF being a circular arc to which is applied the chain EG of the pump. Then whilſt the great wheel is turned by the lever NA from O towards I, the wave Q preſſes down the wheel QR, and raiſes the end E of the lever, and thus draws up the water in the pump G. But when the deepeſt part O of the wave is paſt the higheſt part of the wheel CR, the wheel riſes up into the hollow S, and ſo the chain EG deſcends till the next wave raiſes it again. Thus the paſſage of every wave by the wheel CR cauſes a ſtroke of the pump. If the number of waves be *odd*, and another pump wheel and lever be placed diametrically

oppoſite on the other ſide of the great wheel; then theſe two levers acting by turns, will keep the motion tolerably uniform, and the power at N will have nearly a uniform action. The wheel CR is introduced for the ſake of ſoftening the friction: but it muſt be carefully adjuſted to the magnitude of the waves, or elſe the motion will be hobbling and irregular. On this account the following method of obtaining a reciprocating motion is more uſual.

Inſtead of making the axis AB (fig. 3. pl. II.) in one continued ſtraight line, let it be bent at right angles in the points *d*, *e*, *f*, *g*, *h*, &c. ſo that the portions *ef*, *gh*, ſhall be parallel to AB, and in the courſe of a rotation of the lantern or trundle EF, they will deſcribe cylindrical ſurfaces: if, then, piſtons and their handles I*b*, I*b*, be hung upon the cranks I, I, as the rotatory motion of the trundle EF (when worked by another wheel) proceeds, the piſtons are alternately forced up and down in the pumps; and thus make one complete ſtroke of each pump for every turn of the lantern. It will be adviſable to place pulleys or rollers at *a*, *b*, *a*, *b*, for the handles or chains to work againſt, when the obliquity of the motion of the cranks I, I, carries them out of the vertical poſition.

Other methods of obtaining reciprocating by means of circular motions may be ſeen under the articles *Air-pump* and *Saw-mill.*

7. *To produce a rotatory motion by means of a reciprocating one.* Suppoſe it is required to give to the wheel SVTO (fig. 4. pl. II.) a rotatory motion about the centre C. In the plane of the wheel, attach to a fixed point F as a centre of motion a lever FQ, which may move freely up and down: let a pin be fixed in the wheel as at R; and let an inflexible bar QR hang upon the pin at R at one end, while the other end is attached to the lever FQ by a ſtirrup; the motion being quite eaſy at both ends. Then, while the point Q is raiſed upwards the bar pulls upwards the pin R, and ſo continues to do until the points Q, R, and C, fall in a right line; at that time the effort of the bar to turn the wheel is nothing; but the wheel by its anterior rotation has acquired a quantity of motion which will carry it on in the ſame direction, till by the downward motion of the extremity Q of the lever, the bar begins to *puſh* forward the pin to which it is attached: thus the motion is continued till the points Q, C, and R, are again in a right line, R being now the fartheſt from Q: in this poſition the bar has no tendency to move the wheel along; but here the effort of momentum continues the motion, as before, till the bar begins to draw the point R upwards. And thus a reciprocating motion of the lever FR gives a complete rotation to the wheel; and the velocity of the cir-

cumference of the wheel may be made as rapid as we pleaſe, by making the diſtance CR ſo much the ſmaller in compariſon of CV. If the lever FQ be below the wheel, the general effect will be the ſame, but the particular circumſtances of the motion will ſucceed each other in a contrary order. In practice it is common to ſubſtitute for the pin at R the handle of a bent winch, as repreſented by the dotted lines in the figure. It is not abſolutely neceſſary that the lever and wheel ſhould be in the ſame plane; but deviations from it are not often to be recommended, except in ſmall machinery, ſuch as a common ſpinning wheel worked by the feet, &c. When it is not required to have a complete rotation of the wheel, for every aſcent and deſcent of the lever FQ, we may change the relation of the two motions in any proportion, by the intervention of tooth and pinion work.

8. *To deſcribe a rectilinear reciprocating motion, by means of an angular or circular reciprocating motion.* Let it be propoſed, for example, to move the end F of the beam FH to and fro in the line EC. Fix a beam AB (fig. 9. pl. I.) perpendicularly to the given line EC, and cut in that beam a groove CD equal in length to the beam FH: let the end H of the beam FH be confined by a pin to run along the groove CD; and let two other pins be fixed, one at G the middle point of the beam FH, the other at C the lower point where the reciprocating motion of the point F terminates: take an iron bar CG equal in length to half FH, and let it move upon the pins C and G as joints. Then while the end G of the bar or guide CG moves through the quadrantal arc L *g* GK; the point H of the beam will ſlide along the groove from D to C, and the point F along the line CE from C to E: and when the guide returns from K by G to L, the end F of the beam will return along the line EC. For, when $CG = GF = GH$, ſuppoſing a line drawn from C to F, the angle $FGC = GCH + GHC = 2\,GCH$; and $CGH = GCF + GFC = 2\,GCF$. Hence we have $2\,GCF + 2\,GCH = FGC + HGC = 2$ right angles, and conſequently $GCF + GCH = HCF = 1$ right angle: that is, the point F falls in a right line drawn through C at right angles to CD. And when FH is in any other poſition, as *fh*, the ſame may be ſhewn.

9. *To communicate motion in any direction by wheels, and to conſtruct the wheels for that purpoſe.* This may be done by placing the wheels ſo that their ſhafts or axles ſhall be inclined in given angles, as repreſented in figs. 1 and 7. pl. III. And in this caſe the wheels are ſeldom portions of cylinders, but moſt commonly portions of cones. When the wheels do not make an angle of 90°, the adjuſtment of the ſhape and magnitude of the conic fruſtums which conſtitute the wheels, is known among

millwrights by the name of *bevel-geer* work; a conciſe account of which is here added. If two cones A and B (fig. 2. pl. III), whoſe ſurfaces always touch in a right line, as *a e*, revolve on their axes *a b*, *a c*, rolling the one upon the other; and if the baſes and altitudes of theſe cones be equal, they will perform complete revolutions in one and the ſame time. For ſince the baſes and altitudes are equal, circles on either cone parallel to the baſe, and at equal diſtances from the vertex, as the diſtances *a* 2, *a* 2, for inſtance, will be equal: and therefore while the ſurfaces of the cones roll one upon another, every point in the circumference of one of theſe circles will be brought ſucceſſively into contact with a correſponding point on the circumference of the other, and they will both have revolved in an equal time. The ſame will hold of the correſponding circles at any other equal diſtances from the vertex, *a* 1, *a* 3, *a* 4, &c. and conſequently the two cones will perform their rotations in equal times.

Again, if the cone *a d e* (fig. 3. pl. III.) have the diameter of its baſe double that of the cone *a d f* while their ſlant heights are the ſame; and if theſe two cones turn on their axes *a c*, *a b*, their ſurfaces during the rotation always touching one another in a right line; then, ſince the circumference of the baſe *d e* is double that of the baſe *d f*, and the circumference of every circular ſection parallel to the former baſe, double that of every correſponding ſection parallel to the latter baſe, it follows that when the cone *a f d* has performed one rotation, the cone *a d e* will have made but half a rotation. The times of rotation being in the ratio of their baſes.

In like manner, if the cone *a e d*, (fig. 4. pl. III.) have the diameter of its baſe, to the diameter of the baſe of *a d f*, as *m* to *n*, the ſlant heights being the ſame; and if theſe cones turn upon their axes *a c*, *a b*, their ſurfaces being always in contact in ſome right line as *a d*; then will the time of a complete rotation of the cone *a e d*, be to the time of rotation of *a d f*, as *m* to *n*; and conſequently the number of rotations of the former cone to the number of rotations of the latter in any given time, as *n* to *m*. And if theſe cones were fluted, the flutes diverging continually from the apex *a* to the baſe they would become conical wheels, and conſtitute *bevel-geer*.

10. Thus, if B *b* and B *d* (fig. 5. pl. III.) be the baſes of two cones turning on their axes, having teeth cut in them diverging from the common vertex A to thoſe baſes, ſuch teeth will work freely into one another from one end to the other: but, as ſuch teeth would be very difficult of adjuſtment towards the point A, and becauſe in practice the two axes could not both be properly

fixed to one and the ſame point; it is neceſſary to cut off a portion, as AFE, from the upper part of both cones, and apply the axles to the lower parts in the ſame manner as in common wheels. The great advantages of theſe conical wheels are, that their teeth may be made of any breadth, according to the ſtreſs they are to ſuſtain; and that the friction will be ſmall in compariſon of that occaſioned by moſt other methods of communicating motion in oblique directions.

11. Now, *to determine the dimenſions of two conical wheels to communicate motion in any oblique angle, the following graphic method may be uſed.* Suppoſe *a b* (fig. 6. pl. III.) to repreſent the ſhaft or axle of one wheel, and *d e* the axle of another wheel, the angle *x* in which they interſect each other being equal to the angle in which the motion is propoſed to be communicated: let it be required for the ſhaft *d e* to revolve *m* times while the ſhaft *a b* revolves *n* times; and let the line *i i* be drawn parallel to *d e* at a diſtance equal to the radius of the baſe of the wheel whoſe axle is *d e*. Then draw a line *k k* parallel to *a b*, and at a diſtance *y g* from it, which ſhall be to the diſtance *y h* as *m* to *n*: through *x* the point of interſection of the lines firſt propoſed, and *y* the interſection of the two lines *i i*, *k k*, reſpectively parallel to the two former, draw the line *x y w*, which will be the pitch line of the two conical wheels, or the line in which the teeth of thoſe wheels act upon one another; and *g y*, *h y* will repreſent the exterior radii of the wheels, which will work one againſt the other after the manner ſhewn in fig. 7. where the correſponding parts are marked by the ſame letters. A third ſhaft and wheel may eaſily be applied to communicate motion in a different direction from either of the former: as the ſhaft and wheel *r s t v* in fig. 7.

It is manifeſt from what is done above, that this is nothing more than to divide an angle *h x h* into two parts whoſe ſines ſhall have a given ratio of *m* to *n*: a well-known problem, which ſolved algebraically gives the theorem, 2 ſin. $\frac{1}{2} g x y =$ 2 ſin. $\frac{1}{2} g x h \cdot \frac{m}{m+n}$. (*Simpſon's Select Exerciſes*, pa. 138.). So that all which is required here may be eaſily calculated by the common rules of plane trigonometry; and thus the accuracy of the conſtruction may be eſtabliſhed.

12. *Univerſal joints* (invented by Dr. Hooke) are ſometimes uſed to communicate motion obliquely, inſtead of conical wheels. Fig. 8. pl. III. repreſents a *ſingle* univerſal joint which may be employed where the angle does not exceed 40 degrees, and when the ſhafts are to move with equal velocity. The ſhafts A and B being both connected with a croſs, will move on

the rounds at the points CE and DF, and thus if the ſhaft A is turned round, the ſhaft B will likewiſe turn with a ſimilar motion in its reſpective poſition.

The *double* univerſal joint (fig. 9. pl. III.) conveys motion in different directions when the angle is between 50 and 90 degrees. It is at liberty to move on the rounds at the points G, H, I, K, connected with the ſhaft B; alſo on the points L, M, N, T, connected with the ſhaft A: thus the two ſhafts are ſo connected that one cannot turn without cauſing the other to turn likewiſe. Theſe joints may be conſtructed by a croſs of iron, or with four pins faſtened at right angles upon the circumference of a hoop or of a ſolid ball: they are of great uſe in cotton-mills, where the tumbling ſhafts are continued to a great diſtance from the moving power: for by applying a univerſal joint, the ſhafts may be cut into convenient lengths, and ſo be enabled to overcome a greater reſiſtance.

13. *When the number of teeth in each of two wheels is given, and the diameter of one of them, the diameter of the other ſhould be ſo found that one wheel may drive the other without ſhaking:* and for this purpoſe there will be a different proportion of diameters or of radii, according to the number of teeth which are to be in contact. Let ADE, BDF (fig. 10. pl. III.) repreſent portions of the wheels, C the point where the teeth ought firſt to come into contact: draw CD perpendicular to AB the right line joining the centres of the wheels; and if this be reckoned the radius, CB will be the ſecant of the angle DCB, and AC the ſecant of the angle DCA. Conſequently, CB : CA : : ſecant DCB : ſecant DCA : : coſec. DBC : coſec. DAC. But, the number of teeth in each wheel being given, the angles DBC, DAC, vary as half the number of teeth in contact. Therefore, divide the arch of the ſemicircle, or 180 degrees, by half the number of teeth in each wheel, and proportion the radii of the wheel to the coſecants of the quotients, or of double, or of treble the quotients, according to the depth of the wheels running, viz. according as they are to have two, four, or ſix teeth, in contact; ſo ſhall the motion be regular and free from ſhaking.

In art. 147. of the firſt volume, we deſcribed the beſt forms for the teeth of wheels: in many caſes, however, a ſmall deviation from theſe perfect forms is not of great importance. But in caſes where the utmoſt accuracy is required, as in the pallets of clocks and watches, the form of the teeth muſt be carefully attended to.

14. *To regulate any motion and make it uniform,* one of the moſt obvious methods it that by means of a pendulum and ſcapement. Thus, (fig. 5. pl. II.) as the pendulum AB vibrates, it cauſes EFG to vibrate alſo, about the axis FG: whilſt the pendulum vibrates towards D a tooth of the wheel KL goes off the pallet

I, and another catches the pallet H: and when the pendulum returns towards C, it draws the pallet H off the tooth, and another catches the pallet I; and ſo on alternately. So that, at every vibration of the pendulum, a tooth goes off one or other of the pallets: and, as the vibrations of the pendulum are iſochronous, the teeth move from the pallets uniformly, the whole rotation of the wheel KL is made regularly, and by reaſon of the connection of the teeth and pinions the deſcent of W is uniform, which would otherwiſe have been accelerated.

15. Profeſſor Robiſon has given ſome general obſervations on the conſtruction of machines, and on the regulating of their motions, which appear highly worthy of the reader's attention, and are therefore extracted, as below.

" When heavy ſtampers are to be raiſed, in order to drop on the matters to be pounded, the wipers by which they are lifted ſhould be made of ſuch a form, that the ſtamper may be raiſed by a uniform preſſure, or with a motion almoſt perfectly uniform. If this is not attended to, and the wiper is only a pin ſticking out from the axis, the ſtamper is forced into motion at once. This occaſions violent jolts to the machine, and great ſtrains on its moving parts and their points of ſupport; whereas when they are gradually lifted, the inequality of deſultory motion is never felt at the impelled point of the machine. We have ſeen piſtons moved by means of a double rack on the piſton-rod. A half wheel takes hold of one rack, and raiſes it to the required height. The moment the half wheel has quitted that ſide of the rack, it lays hold of the other ſide, and forces the piſton down again. This is propoſed as a great improvement; correcting the unequable motion of the piſton moved in the common way by a crank. But it is far inferior to the crank motion. It occaſions ſuch abrupt changes of motion, that the machine is ſhaken by jolts. Indeed if the movement were accurately executed, the machine would be ſhaken to pieces, if the parts did not give way by bending and yielding. Accordingly, we have always obſerved that this motion ſoon failed, and was changed for one that was more ſmooth. A judicious engineer will avoid all ſuch ſudden changes of motion, eſpecially in any ponderous part of a machine.

When ſeveral ſtampers, piſtons, or other reciprocal movers, are to be raiſed and depreſſed, common ſenſe teaches us to diſtribute their times of action in a uniform manner, ſo that the machine may always be equally loaded with work. When this is done, and the obſervations in the preceding paragraph attended to, the machine may be made to move almoſt as ſmoothly as if there were no reciprocations in it. Nothing ſhews the ingenuity of the author more than the artful yet ſimple and effectual contrivances for obviating thoſe difficulties that unavoidably ariſe from the very nature of the work that muſt be performed by the machine, and of the power employed.

16. There is alſo great room for ingenuity and good choice in the management of the moving power, when it is ſuch as cannot immediately produce the kind of motion required for effecting the purpoſe. We mentioned the converſion of the continued rotation of an axis into the reciprocating motion of a piſton, and the improvement which was thought to have been made on the common and obvious contrivance of a crank, by ſubſtituting a double rack on the piſton-rod, and the inconvenience ariſing from the jolts occaſioned by this change. We have ſeen a great forge, where the engineer, in order to avoid the ſame inconvenience ariſing from the abrupt motion given to the great ſledge hammer of ſeven hundred weight, reſiſting with a five-fold momentum, formed the wipers into ſpirals, which communicated motion to the hammer almoſt without any jolt whatever; but the reſult was, that the hammer roſe no higher than it had been raiſed in contact with the wiper, and then fell on the iron bloom with very little effect. The cauſe of its inefficiency was not gueſſed at; but it was removed, and wipers of the common form were put in place of the ſpirals. In this operation, the rapid motion of the hammer is abſolutely neceſſary. It is not enough to *lift* it up; it muſt be *toſſed* up, ſo as to fly higher than the wiper lifts it, and to ſtrike with great force the ſtrong oaken ſpring which is placed in its way. It compreſſes this ſpring, and is reflected by it with a conſiderable velocity, ſo as to hit the iron as if it had fallen from a great height. Had it been allowed to fly to that height, it would have fallen upon the iron with ſomewhat more force (becauſe no oaken ſpring is perfectly elaſtic); but this would have required more than twice the time.

17. In employing a power which of neceſſity reciprocates, to drive machinery which requires a continuous motion (as in applying the ſteam engine to a cotton or a griſt mill), there alſo occur great difficulties. The neceſſity of reciprocation in the firſt mover waſtes much power; becauſe the inſtrument which communicates ſuch an enormous force muſt be extremely ſtrong, and be well ſupported. The impelling power is waſted in imparting, and afterwards deſtroying, a vaſt quantity of motion in the working beam. The ſkilful engineer will attend to this, and do his utmoſt to procure the neceſſary ſtrength of this firſt mover, without making it a vaſt load of inert matter. He will alſo remark, that all the ſtrains on it, and on its ſupports, are changing their directions in every ſtroke. This requires particular attention to the manner of ſupporting it. If we obſerve the ſteam engines which have been long erected,

we ſee that they have uniformly ſhaken the building to pieces. This has been owing to the ignorance or inattention of the engineer in this particular. They are much more judiciouſly erected now, experience having taught the moſt ignorant that no building can withſtand their deſultory and oppoſite jolts, and that the great movements muſt be ſupported by a framework independent of the building of maſonry which contains it *.

The engineer will alſo remark, that when a ſingle-ſtroke ſteam engine is made to turn a mill, all the communications of motion change the direction of their preſſure twice every ſtroke. During the working ſtroke of the beam, one ſide of the teeth of the intervening wheels is preſſing the machinery forward; but during the returning ſtroke, the machinery, already in motion, is dragging the beam, and the wheels are acting with the other ſide of the teeth. This occaſions a rattling at every change, and makes it proper to faſhion both ſides of the teeth with the ſame care.

It will frequently conduce to the good performance of an engine, to make the action of the reſiſting work unequable, accommodated to the inequalities of the impelling power. This will produce a more uniform motion in machines in which the momentum of inertia is inconſiderable. There are ſome beautiful ſpecimens of this kind of adjuſtment in the mechaniſm of animal bodies.

18. It is very cuſtomary to add what is called a **Fly** to machines. This is a heavy diſk or hoop, or other maſs of matter *balanced on its axis*, and ſo connected with the machinery as to turn briſkly round with it. This may be done with the view of rendering the motion of the whole more regular, notwithſtanding unavoidable inequalities of the accelerating forces, or of the reſiſtances occaſioned by the work. It becomes a **Regulator.** Suppoſe the reſiſtance extremely unequal, and the impelling power perfectly conſtant; as when a bucket wheel is employed to work *one* pump. When the piſton has ended its working ſtroke, and while it is going down the barrel, the power of the wheel being ſcarcely oppoſed, it accelerates the whole machine, and the piſton arrives at the bottom of the barrel with a conſiderable velocity. But in the riſing again, the wheel is oppoſed

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* The gudgeons of a water-wheel ſhould never reſt on the wall of the building. It ſhakes it; and if ſet up ſoon after the building has been erected, it prevents the mortar from taking firm bond; perhaps by ſhattering the calcareous cryſtals as they form When the engineer is obliged to reſt the gudgeons in this way, they ſhould be ſupported by a block of oak laid a little hollow. This ſoftens all tremors, like ſprings of a wheel carriage. This practice would be very ſerviceable in many other parts of the conſtruction.

by the column of water now preſſing on the piſton. This immediately retards the wheel; and when the piſton has reached the top of the barrel, all the acceleration is undone, and is to begin again. The motion of ſuch a machine is very hobbling: but the ſuperplus of accelerating force at the beginning of a returning ſtroke will not make ſuch a change in the motion of the machine if we connect the fly with it. For the accelerating momentum is a determinate quantity. Therefore, if the radius of the fly be great, this momentum will be attained by communicating a ſmall angular motion to the machine. The momentum of the fly is as the ſquare of its radius; therefore it reſiſts acceleration in this proportion; and although the overplus of power generates the ſame momentum of rotation in the whole machine as before, it makes but a ſmall addition to its velocity. If the diameter of the fly be doubled, the augmentation of rotation will be reduced to one-fourth. Thus, by giving a rapid motion to a ſmall quantity of matter, the great acceleration during the returning ſtroke of the piſton is prevented. This acceleration continues, however, during the whole of the returning ſtroke, and at the end of it the machine has acquired its greateſt velocity. Now the working ſtroke begins, and the overplus of power is at an end. The machine accelerates no more; but if the power is juſt in equilibrio with the reſiſtance, it keeps the velocity which it has acquired, and is ſtill more accelerated during the *next* returning ſtroke. But now, at the beginning of the ſubſequent working ſtroke, there is an overplus of reſiſtance, and a retardation begins, and continues during the whole riſe of the piſton; but it is conſiderable in compariſon of what it would have been without the fly; for the fly, retaining its acquired momentum, drags forward the reſt of the machine, aiding the impelling power of the wheel. It does this by all the communications taking into each other in the oppoſite direction. The teeth of the intervening wheels are heard to drop from their former contact on one ſide, to a contact on the other. By conſidering this proceſs with attention, we eaſily perceive that, in a few ſtrokes, the overplus of power during the returning ſtroke comes to be ſo adjuſted to the deficiency during the working ſtroke, that the accelerations and retardations exactly deſtroy each other, and every ſucceeding ſtroke is made with the ſame velocity, and an equal number of ſtrokes is made in every ſucceeding minute. Thus the machine acquires a general uniformity with periodical inequalities. It is plain, that by ſufficiently enlarging either the diameter or the weight of the fly, the irregularity of the motion may be rendered as ſmall as we pleaſe. It is much better to enlarge the diameter. This preſerves the friction more moderate, and the pivot wears leſs. For theſe reaſons, a fly is in general a conſiderable improvement in machinery, by equaliſing many exertions that are naturally very irregular. Thus, a man working at a common windlaſs exerts a very irregular preſſure on the winch. In one of his poſitions in each turn he can exert a force of near 70 pounds without fatigue, but in another he cannot exert above 25; nor muſt he be loaded with much above this in general. But if a large fly be connected properly with the windlaſs, he will act with equal eaſe and ſpeed againſt 30 pounds.

This regulating power of the fly is without bounds, and may be uſed to render uniform a motion produced by the moſt deſultory and irregular power. It is thus that the moſt regular motion is given to mills that are driven by a ſingle-ſtroke ſteam engine, where for two or even three ſeconds there is no force preſſing round the mill. The communication is made through a maſſive fly of very great diameter, whirling with great rapidity. As ſoon as the impulſe ceaſes, the fly, continuing its motion, urges round the whole machinery with almoſt unabated ſpeed. At this inſtant all the teeth, and all the joints, between the fly and the firſt mover, are heard to catch in the oppoſite direction.

If any permanent change ſhould happen in the impelling power, or in the reſiſtance, the fly makes no obſtacle to its producing its full effect on the machine; and it will be obſerved to accelerate or retard uniformly, till a new general ſpeed is acquired exactly correſponding with this new power and reſiſtance.

19. Many machines include in their conſtruction movements which are equivalent with this intentional regulator. A flour mill, for example, cannot be better regulated than by its milſtone; but in the Albion mills, a heavy fly was added with great propriety; for if the mills had been regulated by their milſtones only, then at every change of ſtroke in the ſteam engine, the whole train of communications between the beam, which is the firſt mover, and the regulating milſtone, which is the very laſt mover, would take in the oppoſite direction. Although each drop in the teeth and joints be but a trifle, the whole, added together, would make a conſiderable jolt. This is avoided by a regulator immediately adjoining to the beam. This continually preſſes the working machinery in one direction. So judiciouſly were the movements of that noble machine contrived, and ſo nicely were they executed, that not the leaſt noiſe was heard, nor the ſlighteſt tremor felt in the building.

20. Mr. Valoué's beautiful pile engine employed at Weſtminiſter Bridge is another remarkable inſtance of the regulating power of a fly. When the ram is dropped, and its follower

diſengaged immediately after it, the horſes would inſtantly tumble down, becauſe the load, againſt which they had been ſtraining hard, is at once taken off; but the gin is connected with a very large fly, which checks any remarkable acceleration, allowing the horſes to lean on it during the deſcent of the load; after which their draught recommences immediately. The ſpindles, cards, and bobbins, of a cotton mill, are alſo a ſort of flies. Indeed all bulky machines of the rotative kind tend to preſerve their motion with ſome degree of ſteadineſs, and their great momentum of inertia is as uſeful in this reſpect as it is prejudicial to the acceleration or any reciprocation when wanted.

21. There is another kind of regulating fly, conſiſting of wings whirled briſkly round till the reſiſtance of the air prevents any great acceleration. This is a very bad one for a *working* machine, for it produces its effect by *really waſting* a part of the moving power. Frequently it employs a very great and unknown part of it, and robs the proprietor of much work. It ſhould never be introduced into any machine employed in manufactures.

22. Some rare caſes occur where a very different regulator is required: where a certain determined velocity is found neceſſary. In this caſe the machine is furniſhed, at its extreme mover, with a conical pendulum, conſiſting of two heavy balls hanging by rods, which move in very nice and ſteady joints at the top of a vertical axis. It is well known, that when this axis turns round, with an angular velocity ſuited to the length of thoſe pendulums, the time of a revolution is determined. Thus, if the length of each pendulum be 39$\frac{1}{5}$ inches, the axis will make a revolution in two ſeconds very nearly. If we attempt to force it more ſwiftly round, the balls will recede a little from the axis, but it employs as long time for a revolution as before; and we cannot make it turn ſwifter, unleſs the impelling power be increaſed beyond all probability; in which caſe the pendulum will fly out from the centre till the rods are horizontal, after which every increaſe of power will accelerate the machine very ſenſibly. Watt and Boulton have applied this contrivance with great ingenuity to their ſteam engines, when they are employed for driving machinery for manufactures which have a very changeable reſiſtance, and where a certain ſpeed cannot be much departed from without great inconvenience. They have connected this receſs of the balls from the axis (which gives immediate indication of an increaſe of power or a diminution of reſiſtance) with the cock which admits the ſteam to the working cylinder. The balls flying out cauſe the cock to cloſe a little, and diminiſh

the ſupply of ſteam. The impelling power diminiſhes the next moment, and the balls again approach the axis, and the rotation goes on as before, although there may have occurred a very great exceſs or deficiency of power.

23. A fly is ſometimes employed for a very different purpoſe from that of a regulator of motion—it is employed as a *collector of power*. Suppoſe all reſiſtance removed from the working point of a machine furniſhed with a very large or heavy fly immediately connected with the working point. When a ſmall force is applied to the impelled point of this machine, motion will begin in the machine, and the fly begin to turn. Continue to preſs uniformly, and the machine will accelerate. This may be continued till the fly has acquired a very rapid motion. If at this moment a reſiſting body be applied to the working point, it will be acted on with very great force; for the fly has now accumulated in its circumference a very great momentum. If a body were expoſed immediately to the action of this circumference, it would be violently ſtruck. Much more will it be ſo, if the body be expoſed to the action of the working point, which perhaps makes one turn while the fly makes a hundred. It will exert a hundred times more force there (very nearly) than at its own circumference. All the motion which has been accumulated on the fly during the whole progreſs of its acceleration is exerted in an inſtant at the working point, multiplied by the momentum depending on the proportion of the parts of the machine. It is thus that the coining preſs performs its office; nay, it is thus that the blackſmith forges a bar of iron. Swinging the great ſledge hammer round his head, and urging it with force the whole way, this accumulated motion is at once extinguiſhed by impact on the iron. It is thus alſo we drive a nail, &c. This accumulating power of a fly has occaſioned many to imagine that a fly really adds power or mechanical force to an engine; and, not underſtanding on what its efficacy depends, they often place the fly in a ſituation where it only adds a uſeleſs burden to the machine. It ſhould always be made to move with rapidity. If intended for a mere regulator, it ſhould be near the firſt mover: and if it be intended to accumulate force in the working point, it ſhould not be far ſeparated from it. In a certain ſenſe, a fly may be ſaid to add power to a machine, becauſe by accumulating into the exertion of one moment the exertions of many, we can ſometimes overcome an obſtacle that we never could have balanced by the ſame machine unaided by the fly. And it is this accumulation of force which gives ſuch an appearance of power to ſome of our firſt movers. See *Supplement*, *Encyclopædia*, *Britan.* art. *Machinery*.

On Friction, and the Stiffneſs of Ropes.

24. Moſt of the propoſitions laid down in the firſt volume of this work have been conducted upon the ſuppoſition that all bodies are perfectly ſmooth, that they ſlide over one another without any friction, and that cords and ropes are perfectly flexible. But ſince there is no ſuch thing as perfect ſmoothneſs in bodies, no machine can move without a mutual rubbing of its parts, at all points of communication: and when we conſider the mode of operation of the teeth of wheel work, the wipers and lifts, the gudgeons of the different axes, &c. we ſhall ſee that *friction*, by which we mean the reſiſtance a body meets with from the ſurface on which it moves, has conſiderable effect in retarding the motion of machines, or gives occaſion for the exertion of much more power in order that the machine may move with the requiſite velocity. Indeed in many machines, as poliſhing mills, grinding mills, boring and ſawing mills, the ultimate taſk performed is either friction or very much reſembles it. So that ſome knowledge of the nature of friction ſeems abſolutely neceſſary, to enable us to apply the principles of the ſimple theory to any uſeful practical purpoſe.

25. Much attention has, therefore, been paid to this ſubject by many ingenious men; but as yet their labours have not greatly added to the ſtock of knowledge as to the real nature of friction: and although ſome ingenious theories have been deduced from the experiments which have already been made, they reſt upon very limited hypotheſes, and are of little, if any, actual utility. This being our opinion, the reader will not expect a minute expoſition of the theory in this place. We ſhall merely preſent a ſingle propoſition, which tends to an obvious practical purpoſe, and does not require the admiſſion of more than one new principle, viz. *that the friction varies nearly as the preſſure.*

Prop. *A power which moves a body along a horizontal plane, acts with the greateſt advantage when the line of direction makes an angle of about* $18\frac{1}{2}°$ *with the plane.* Let B (fig. 2. pl. I.) be the body which is to be moved along the horizontal plane BC, by a given power eſtimated in quantity and direction by BA. Demit the perpendicular AC; and let the given line $AB = 1 =$ radius, $AC =$ ſine $\angle ABC = x$, $BC = \sqrt{1 - x^2} =$ the force moving the body horizontally. The power by its oblique action diminiſhes the preſſure of the weight on the horizontal plane in the ratio of $1 : x$, therefore $Bx =$ that part of the preſſure which is taken off, and the actual preſſure $= B - Bx$. Let friction be =

$\frac{m}{n}$th part of the weight or preſſure: that is, let it be $=\frac{m}{n}\text{B}-\frac{m}{n}\text{B}x$. Then the force requiſite to move B horizontally muſt be equal to the horizontal force diminiſhed by friction, or $=\text{B}(1-x^2)^{\frac{1}{2}}-\frac{m}{n}\text{B}+\frac{m}{n}\text{B}x$. This is to be a minimum, or its fluxion $\frac{m}{n}\text{B}\dot{x}-\frac{\text{B}x\dot{x}}{(1-x^2)^{\frac{1}{2}}}=0$: hence we find $x=\frac{m}{(m^2+n^2)^{\frac{1}{2}}}=$ ſine of the angle ABC. And if, as has been concluded from many experiments, $\frac{m}{n}=\frac{1}{3}$, then will $x=\frac{1}{\sqrt{10}}=$ ſine of 18° 26′ nearly.

If the plane along which the body is to be moved be inclined to the horizon, the ſine of the angle which the line of direction or traction of the power makes with the plane, when it acts with the greateſt advantage, will be nearly $=\frac{c}{c^2+9}$, c being the coſine of the angle of elevation to radius = unity.

26. The principle aſſumed in the inveſtigation above is, however, by no means *general* in its application: as there are many circumſtances which modify the operation of friction, and cauſe deviations from this law. Theſe circumſtances will be beſt learnt by reflecting upon ſome of the experiments which have been made relative to the friction of bodies in motion. Of ſuch experiments we ſhall firſt deſcribe thoſe of Mr. Profeſſor Vince, which were conducted with great care and ingenuity, and led to ſome important reſults. The object of this philoſopher was to determine the following queſtions:

1. Whether friction be a uniformly retarding force?
2. What is the quantity of friction?
3. Whether the friction varies in proportion to the preſſure or weight?
4. Whether the friction be the ſame on whichever of its ſurfaces a body moves?

(1.) With reſpect to the firſt of theſe queſtions, the author truly obſerves, that if friction be a uniform force, the difference between it and the given force of the moving power employed to overcome it muſt alſo be uniform; and that therefore the moving power, if it be a body deſcending by its own weight, muſt deſcend with a uniformly accelerated velocity, juſt as when there was no friction. The ſpaces deſcribed from the beginning of the motion will indeed be diminiſhed in any given time on account of the friction; but ſtill they muſt be to each other as the ſquares of the times employed.

(2.) A plane was therefore adjuſted parallel to the horizon, at the extremity of which was placed a pulley, which could be elevated or depreſſed, in order to render the ſtring which connected the body and the moving force parallel to the plane. A ſcale accurately divided was placed by the ſide of the pulley perpendicular to the horizon, by the ſide of which the moving force deſcended; upon the ſcale was placed a moveable ſtage, which could be adjuſted to the ſpace through which the moving force deſcended in any given time; which time was meaſured by a well-regulated pendulum clock vibrating ſeconds. Every thing being thus prepared, the following experiments were made to aſcertain the law of friction.

(3.) *Exp.* 1. A body was placed upon the horizontal plane, and a moving force applied, which, from repeated trials, was found to deſcend 52¼ inches in 4″; for by the beat of the clock, and the ſound of the moving force when it arrived at the ſtage, the ſpace could be very accurately adjuſted to the time: the ſtage was then removed to that point to which the moving force would deſcend in 3″, upon ſuppoſition, that the ſpaces deſcribed by the moving power were as the ſquares of the times; and the ſpace was found to agree very accurately with the time: the ſtage was then removed to that point to which the moving force ought to deſcend in 2″, upon the ſame ſuppoſition, and the deſcent was found to agree exactly with the time: laſtly, the ſtage was adjuſted to that point to which the moving force ought to deſcend in 1″, upon the ſame ſuppoſition, and the ſpace was obſerved to agree with the time. Now, in order to find whether a difference in the time of deſcent could be obſerved by removing the ſtage a little above and below the poſitions which correſponded to the above times, the experiment was tried, and the deſcent was always found too ſoon in the former, and too late in the latter caſe; by which the author was aſſured, that the ſpaces firſt mentioned correſponded exactly to the times. And, for the greater certainty, each deſcent was repeated eight or ten times; and every caution uſed in this experiment was alſo made uſe of in all the following.

Exp. 2. A ſecond body was laid upon the horizontal plane, and a moving force applied which deſcended 41¼ inches in 3″; the ſtage was then adjuſted to the ſpace correſponding to 2″, upon ſuppoſition that the ſpaces deſcended through were as the ſquares of the times, and it was found to agree accurately with the time; the ſtage was then adjuſted to the ſpace correſponding to 1″, upon the ſame ſuppoſition; and it was found to agree with the time.

Exp. 3. A third body was laid upon the horizontal plane, and a moving force applied, which deſcended $59\frac{1}{2}$ inches in 4″; the ſtage was then adjuſted to the ſpace correſponding to 3″, upon ſuppoſition that the ſpaces deſcended through were as the ſquares of the times, and it was found to agree with the time; the ſtage was then adjuſted to the ſpace correſponding to 2″, upon the ſame ſuppoſition, and it was found to agree with the time; the ſtage was then adjuſted to the ſpace correſponding to 1″, and was found to agree with the time.

Exp. 4. A fourth body was then taken and laid upon the horizontal plane, and a moving force applied, which deſcended 55 inches in 4″; the ſtage was then adjuſted to the ſpace through which it ought to deſcend in 3″, upon ſuppoſition that the ſpaces deſcended through were as the ſquares of the times, and it was found to agree with the time; the ſtage was then adjuſted to the ſpace correſponding to 2″, upon the ſame ſuppoſition, and was found to agree with the time; laſtly, the ſtage was adjuſted to the ſpace correſponding to 1″, and it was found to agree exactly with the time.

Beſides theſe experiments, a great number of others were made with hard bodies, or thoſe whoſe parts ſo firmly cohered as not to be moved *inter ſe* by the friction; and in each experiment, bodies of very different degrees of friction were choſen, and the reſults all agreed with thoſe related above; it was therefore concluded, that *the friction of hard bodies in motion is a uniformly retarding force.*

But to determine whether the ſame was true for bodies when covered with cloth, woollen, &c. experiments were made in order to aſcertain it; when it was found in all caſes, that the retarding force increaſed with the velocity; but, upon covering bodies with paper, the conſequences were found to agree with thoſe related above.

(4.) Having proved that the retarding force of all hard bodies ariſing from friction is uniform, the quantity of friction, conſidered as equivalent to a weight without inertia drawing the body on the horizontal plane backwards, or acting contrary to the moving force, may be immediately deduced from the foregoing experiments. For let M = the moving force expreſſed by its weight; F = the friction; W = the weight of the body upon the horizontal plane; S = the ſpace through which the moving force deſcended in the time t expreſſed in ſeconds; $r = 16\frac{1}{12}$ feet; then the whole accelerative force (the force of gravity being unity) will be $\frac{M-F}{M+W}$; hence, by the laws of uniformly accelerated motions, $\frac{M-F}{M+W} \times rt^2 = S$, conſequently $F = M - \frac{\overline{M+W} \times S}{rt^2}$. To exemplify this, let us take the caſe of the laſt experiment, where $M=7$, $W=25\frac{3}{4}$, $S=4\frac{7}{12}$ feet, $t=4''$; hence $F=7-\frac{32\frac{3}{4}\times 4\frac{7}{12}}{16\frac{1}{12}\times 16}=6.417$; conſequently the friction was to the weight of the rubbing body as 6.4167 to 25.75. And the great accuracy of determining the friction by this method is manifeſt from hence, that if an error of 1 inch had been made in the deſcent (and experiments carefully made may always determine the ſpace to a much greater exactneſs) it would not have affected the concluſion $\frac{1}{600}$ part of the whole.

(5.) We come in the next place to determine, whether friction, *cæteris paribus*, varies in proportion to the weight or preſſure. Now if the whole quantity of the friction of a body, meaſured by a weight without inertia equivalent to the friction drawing the body backwards, increaſes in proportion to its weight, it is manifeſt, that the retardation of the velocity of the body ariſing from the friction will not be altered; for the retardation varies as $\frac{\text{Quantity of friction}}{\text{Quantity of matter}}$; hence, if a body be put in motion upon the horizontal plane by any moving force, if both the weight of the body and the moving force be increaſed in the ſame ratio, the acceleration ariſing from that moving force will remain the ſame, becauſe the accelerative force varies as the moving force divided by the whole quantity of matter, and both are increaſed in the ſame ratio; and if the quantity of friction increaſes alſo as the weight, then the retardation ariſing from the friction will, from what has been ſaid, remain the ſame, and therefore the whole acceleration of the body will not be altered; conſequently the body ought, upon this ſuppoſition, ſtill to deſcribe the ſame ſpace in the ſame time. Hence, by obſerving the ſpaces deſcribed in the ſame time, when both the body and the moving force are increaſed in the ſame ratio, we may determine whether the friction increaſes in proportion to the weight. The following experiments were therefore made in order to aſcertain this matter.

Exp. 1. A body weighing 10 oz. by a moving force of 4 oz. deſcribed in 2″ a ſpace of 51 inches; by loading the body with 10 oz. and the moving force with 4 oz. it deſcribed 56 inches in 2″; and by loading the body again with 10 oz. and the moving force with 4 oz. it deſcribed 63 inches in 2″.

Exp. 2. A body whoſe weight was 16 oz. by a moving force of 5 oz. deſcribed a ſpace of 49 inches in 3″; and by loading the body with 64 oz. and the moving force with 20 oz. the ſpace deſcribed in the ſame time was 64 inches.

Exp. 3. A body weighing 6 oz. by a moving force of 2½ oz. deſcribed 28 inches in 2″; and by loading the body with 24 oz.

and the moving force with 10 oz. the ſpace deſcribed in the ſame time was 54 inches.

Exp. 4. A body weighing 8 oz. by a moving force of 4 oz. deſcribed $33\frac{1}{2}$ inches in 2″; and by loading the body with 8 oz. and the moving force with 4 oz. the ſpace deſcribed in the ſame time was 47 inches.

Exp. 5. A body whoſe weight was 9 oz. by a moving force of $4\frac{1}{2}$ oz. deſcribed 48 inches in 2″; and by loading the body with 9 oz. and the moving force with $4\frac{1}{2}$ oz. the ſpace deſcribed in the ſame time was 60 inches.

Exp. 6. A body weighing 10 oz. by a moving force of 3 oz. deſcribed 20 inches in 2″; by loading the body with 10 oz. and the moving force with 3 oz. the ſpace deſcribed in the ſame time was 31 inches; and by loading the body again with 30 oz. and the moving force with 9 oz. the ſpace deſcribed was 34 inches in 2″.

From theſe experiments, and many others which it is not neceſſary here to relate, it appears, that the ſpace deſcribed is always increaſed by increaſing the weight of the body and the accelerative force in the ſame ratio; and as the acceleration ariſing from the moving force continued the ſame, it is manifeſt, that the retardation ariſing from the friction muſt have been diminiſhed, for the whole accelerative force muſt have been increaſed on account of the increaſe of the ſpace deſcribed in the ſame time; and hence (as the retardation from friction varies as $\frac{\text{Quantity of friction}}{\text{Quantity of matter}}$) *the quantity of friction increaſes in a leſs ratio than the quantity of matter or weight of the body.*

(6.) We come now to the laſt thing which it was propoſed to determine, that is, whether the friction varies by varying the ſurface on which the body moves. Let us call two of the ſurfaces A and *a*, the former being the greater, and the latter the leſs. Now the weight on every given part of *a* is as much greater than the weight on an equal part of A, as A is greater than *a*; if therefore the friction was in proportion to the weight, *cæteris paribus*, it is manifeſt, that the friction on *a* would be equal to the friction on A, the whole friction being, upon ſuch a ſuppoſition, as the weight on any given part of each ſurface multiplied into the number of ſuch parts or into the whole area, which products, from the proportion above, are equal. But from the laſt experiments it has been proved, that the friction on any given ſurface increaſes in a leſs ratio than the weight; conſequently the friction on any given part of *a* has a leſs ratio to the friction on an equal part of A than A has to *a*, and hence the friction on *a* is leſs than the friction on A, that is, the ſmalleſt ſurface has always the leaſt friction.

As this concluſion is contrary to the generally received opinion, Mr. Vince though it proper to confirm it by a ſet of experiments made with different bodies of exactly the ſame degree of roughneſs on their two ſurfaces.

Exp. 1. A body was taken whoſe flat ſurface was to its edge as 22 : 9, and with the ſame moving force the body deſcribed on its flat ſide 33½ inches in 2″, and on its edge 47 inches in the ſame time.

Exp. 2. A ſecond body was taken whoſe flat ſurface was to its edge as 32 : 3, and with the ſame moving force it deſcribed on its flat ſide 32 inches in 2″, and on its edge it deſcribed 37½ inches in the ſame time.

Exp. 3. He took another body and covered one of its ſurfaces, whoſe length was 9 inches, with a fine rough paper, and by applying a moving force, it deſcribed 25 inches in 2″; he then took off ſome paper from the middle, leaving only ⅜ of an inch at the two ends, and with the ſame moving force it deſcribed 40 inches in the ſame time.

Exp. 4. Another body was taken which had one of its ſurfaces, whoſe length was 9 inches, covered with a fine rough paper, and by applying a moving force it deſcribed 42 inches in 2″; ſome of the paper was then taken off from the middle, leaving only 1⅜ inches at the two ends, and with the ſame moving force it deſcribed 54 inches in 2″; he then took off more paper, leaving only ¼ of an inch at the two ends, and the body then deſcribed, by the ſame moving force, 60 inches in the ſame time.

In the two laſt experiments the paper which was taken off the ſurface was laid on the body, that its weight might not be altered.

Exp. 5. A body was taken whoſe flat ſurface was to its edge as 30 : 17; the *flat* ſide was laid upon the horizontal plane, a moving force was applied, and the ſtage was fixed in order to ſtop the moving force, in conſequence of which the body would then go on with the velocity acquired until the friction had deſtroyed all its motion; when it appeared from a mean of 12 trials that the body moved, after its acceleration ceaſed, 5⅖ inches before it ſtopped. The *edge* was then applied, and the moving force deſcended through the ſame ſpace; and it was found, from a mean of the ſame number of trials, that the ſpace deſcribed was 7⅓ inches before the body loſt all its motion, after it ceaſed to be accelerated.

Exp. 6. Another body was then taken whoſe flat ſurface was to its edge as 60 : 19, and by proceeding as before, on the flat ſurface it deſcribed, at a mean of 12 trials, 5⅓ inches, and on the edge $6\frac{11}{24}$ inches, before it ſtopped, after the acceleration ceaſed.

Exp. 7. Another body was taken whoſe flat ſurface was to its edge as 26 : 3, and the ſpaces deſcribed on theſe two ſurfaces, after the acceleration ended, were, at a mean of ten trials, $4\frac{3}{7}$ and $7\frac{7}{10}$ inches reſpectively.

From all theſe different experiments its appears, that the ſmalleſt ſurface had always the leaſt friction, which agrees with the conſequence deduced from the conſideration that the friction does not increaſe in ſo great a ratio as the weight; we may therefore conclude, that *the friction of a body does not continue the ſame when it has different ſurfaces applied to the plane on which it moves, but that the ſmalleſt ſurface will have the leaſt friction.*

To the experiments inſtituted by Mr. Ferguſon and others, from which concluſions have been drawn ſo different from theſe, this author makes the following objections: It was their object to find what moving force would *juſt* put a body at reſt in motion; and having, as they thought, found it, they thence concluded, that the accelerative force was then equal to the friction. But it is manifeſt, as Mr. Vince obſerves, that any force which will put a body in motion muſt be *greater* than the force which oppoſes its motion, otherwiſe it could not overcome it; and hence, if there were no other objection than this, it is evident, that the friction could not be very accurately obtained: but there is another objection, which totally deſtroys the experiment ſo far as it tends to ſhew the quantity of friction, which is the ſtrong coheſion of the body to the plane when it lies at reſt; and this is confirmed by the following experiments. 1ſt, A body of $12\frac{3}{4}$ oz. was laid upon an horizontal plane, and then loaded with a weight of 8lb. and ſuch a moving force was applied as would, when the body was juſt *put* in motion, continue that motion without any acceleration; in which caſe the friction muſt be juſt equal to the accelerative force. The body was then ſtopped, when it appeared, that the ſame moving force which had *kept* the body in motion before would not *put* it in motion, and it was found neceſſary to take off $4\frac{1}{2}$ oz. from the body before the ſame moving force *would* put it in motion; it appears, therefore, that this body, when laid upon the plane at reſt, acquired a very ſtrong coheſion to it. 2dly, a body whoſe weight was 16 oz. was laid at reſt upon the horizontal plane, and it was found that a moving force of 6 oz. would juſt *put* it in motion; but that a moving force of 4 oz. *would*, when it was juſt put in motion, *continue* that motion without any acceleration, and therefore the accelerative force muſt *then* have been equal to the friction, and not when the moving force of 6 oz. was applied.

From theſe experiments therefore it appears, how very conſiderable the coheſion was in proportion to the friction when the body was in motion; it being, in the latter caſe, almoſt $\frac{1}{3}$, and in the former it was found to be very nearly equal to the whole friction. All the concluſions therefore deduced from the experiments, which have been inſtituted to determine the friction from the force neceſſary to *put* a body in motion (and very few have been deſcribed but upon ſuch a principle), have manifeſtly been totally falſe; as ſuch experiments only ſhew the reſiſtance which ariſes from the coheſion and friction conjointly.

Mr. Vince concludes this part of the ſubject with a remark upon art. 5. "It appears (ſays he) from all the experiments which I have made, that the proportion of the increaſe of the friction to the increaſe of the weight was different in all the different bodies which were made uſe of; no general rule therefore can be eſtabliſhed to determine this for *all* bodies, and the experiments which I have hitherto made have not been ſufficient to determine it for the *ſame* body."

Such are the reſults of Mr. Vince's ingenious experiments. He founds upon them a theory which the curious reader may peruſe in the *Philoſophical Tranſactions*, Vol. 75. or Nos. 65. 66. of *Tilloch's Philoſophical Magazine*, but which is not inſerted here, as it does not ſeem readily applicable to any practical caſes.

27. An ingenious engineer, Mr. John Southern of Birmingham, made a ſeries of experiments upon mills uſed for turning grindſtones, with a view of corroborating Mr. Vince's poſition that *Friction is a uniform retarding force.* And theſe experiments are the more worthy of notice as they were made on *heavy* machinery, with conſiderable variation of velocity of the rubbing ſurface, and great ſpaces rubbed over: the weight which cauſed the friction being upwards of 33 cwt., the velocity of the rubbing ſurfaces 4 feet per ſecond at the greateſt, and the length of ſurface rubbed over about 1000 feet at a medium. Theſe experiments ſeem to confirm the opinion that friction is a uniform reſiſtance, at leaſt where the rubbing ſurface moves with a velocity of from 9 inches to 4 feet per ſecond; and Mr. Southern concludes from them, that in favourable caſes it does not exceed *the fortieth part of the preſſure or weight that occaſions it.*

The experiments from which theſe inferences are deduced, are deſcribed in No. 66 of the Philoſophical Magazine juſt referred to.

28. *M. Coulumb* has an extenſive paper on the ſubject of Friction, in vol. 10. "*Des Memoires des Savants étrangers;*" where he deſcribes his experiments at conſiderable length, and deduces

from them an elaborate theory. We cannot here enter into the detail of all theſe experiments: but ſhall merely ſtate M. Coulumb's principal reſults.

This gentleman's concluſions are widely different from Mr. Vince's in one important particular: for he aſſerts that *(cæteris paribus) the friction is proportional to the preſſure.* The mean ratios of friction to preſſure, given by M. Coulumb's experiments for different kinds of wood, are as follow, the preſſure being denoted by unity.

Oak againſt oak . . .	0·43
Oak againſt fir . . .	0·65
Fir againſt fir	0·56
Elm againſt elm . . .	0·47

the friction being made in the direction of the threads or fibres of the wood. But when the friction is made *acroſs* the grain of the wood, or ſo that the direction of the fibres forms a right angle with that of the motion, the friction is leſs than in the former caſe, but ſtill in a conſtant ratio to the preſſure; the reſults being then as below:

Oak againſt fir . . .	0·158
Fir againſt fir	0·167
Elm againſt elm . . .	0·100

Theſe ratios are conſtant quantities, not depending upon the velocities, except in the caſe of elm when the preſſures are very ſmall, for then the friction increaſes ſenſibly with the velocity.

M. Coulumb gives the following general ſummary.

"(1.) The friction of wood ſliding over wood (both being dry) oppoſes after a ſufficient time of quieſcence a reſiſtance proportional to the preſſure; that reſiſtance ſenſibly increaſing in the firſt inſtants of repoſe: but after ſome minutes it uſually arrives at its maximum or its limit.

"(2.) When wood glides dry over wood with any velocity whatever, the friction is ſtill proportional to the preſſure; but its intenſity is much leſs than that which is experienced in detaching the ſurfaces after ſome minutes of reſt: it has been found, for example, that the force neceſſary to detach and produce a ſliding motion in two ſurfaces of oak after ſome minutes of quieſcence, is to that neceſſary to overcome the friction when the ſurfaces have obtained any degree of velocity whatever, nearly as 9 to 2.

"(3.) The friction of metals ſliding over metals, without oiling, is alſo proportional to the preſſures; but its intenſity is the ſame, whether the ſurfaces are detached after having been any time in repoſe, or whether they preſerve any uniform velocity whatever.

"(4.) Heterogeneous ſurfaces, ſuch as woods and metals ſliding the one over the other, without oiled ſurfaces, give for their friction reſults very different from the preceding ones: for the intenſity of their friction relatively to the time of repoſe increaſes ſlowly, and does not attain its limit till after four or five days, and ſometimes more; inſtead of which, in metals the limit is attained in an inſtant, and in wood in a few minutes: this augmentation is even ſo ſlow that the reſiſtance due to the friction in inſenſible velocities is almoſt the ſame as that which we muſt ſurmount in moving or detaching the ſurfaces after three or four ſeconds of reſt. And this is not all: in wood gliding unoiled over wood, and in metals ſliding over metals, the velocity has very little influence upon the friction; but here the friction increaſes very ſenſibly in proportion as the velocities are augmented; in ſuch manner that the friction increaſes nearly according to an arithmetical progreſſion, when the velocities increaſe in a geometrical progreſſion."

The ratio of the friction to the preſſure (1) when oak was made to ſlide over iron, was found, from forty experiments, to be as here ſtated: when the velocity was almoſt inſenſible, ·0894, ·0773, ·0785, and ·0736: when the velocity was about a foot per ſecond, ·1698, ·1722, ·1817, and ·1573.

29. When metals ſlide upon wood done over with greaſe, the friction, ſays M. Coulumb, "appears much ſoftened, and we may produce inſenſible velocities with degrees of traction leſs conſiderable than in all the other ſpecies of friction; but when the velocities have been a little augmented, we have found that the friction increaſes greatly with reſpect to the velocity, as was the caſe when we made unoiled metals ſlide upon wood; and we have, for the relation of the augmentation of velocities and the degree of traction which produced that augmentation, nearly the ſame law with that we ſought to determine in the friction of metals ſliding *dry* upon wood: but if the greaſing be not renewed at each experiment, it coagulates, changes its nature, and the friction ſucceſſively augments."

"When the ſurfaces are done over with tallow, the ratio of the friction to the preſſure is greater under preſſures of about 50 pounds, than under greater preſſures.

"With coatings (*enduits*, plaſters) of cart-greaſe the friction is never leſs than 1/9 of the preſſure. Its reſiſtance depends upon the conſiſtence of the coating, and the friction augments ſenſibly as this coating is ſofter. When the ſurfaces are done over with tallow, and are of great extent, the friction corrupts or changes the nature of the tallow, and augments ſenſibly as we continue the motion without renewing the coating: yet it is always found leſs than 1/8 of the preſſure. But when the tallow is diſſolved to an oil, this effect is leſs ſenſible."

M. Coulumb's experiments on the friction of *axes* will be deſcribed farther on.

On comparing the reſults of Mr. Vince's experiments with thoſe of M. Coulumb's, already referred to, it will be ſeen that our knowledge on this branch of the ſubject is very far from being ſo certain and ſatisfactory as is deſirable. We may, however, now deduce a few practical inferences from the preceding articles.

(1.) Friction is diminiſhed by making the ſurfaces ſmooth which move upon each other. But there is a limit to this ſmoothneſs: for the ſurfaces may be ſo highly poliſhed as to render the attraction of coheſion very ſenſible.

(2.) Friction is diminiſhed by anointing the rubbing ſurfaces with ſome unctuous matter. Thus, in wood acting againſt wood, olive oil reduces the friction to nearly its half, and metals oiled have leſs friction than when poliſhed.

(3.) Friction is diminiſhed by diminiſhing the ſurfaces in contact. But this has a limit: for if the moving ſurface be very thin, and the other ſoft, the former will plough a groove in the latter, and thus have the friction increaſed.

(4.) Friction is diminiſhed by diſpoſing the parts of a machine in ſuch a manner, that the ratio of the velocity of the parts which rub againſt each other to the velocity of the power, may be as ſmall as poſſible.

(5.) Friction is greatly diminiſhed by cauſing the body to roll inſtead of ſliding along the ſurface. This is in fact a diſtinct ſpecies of friction, and will come under conſideration more fully ſoon.

(6.) Hence in machines, leſt the friction ſhould employ a great part of the power, care is to be taken that no part of the machine *ſlide* along another if it can be avoided; but rather that the parts ſhould roll or turn upon each other. With this view it will be proper to lay the axes of cylinders, &c. not in a groove or concave matrix, as uſual, but upon a horizontal bar with two vertical pieces to keep ſuch axes from rolling off, or, between little wheels called *friction* wheels, moveable on their reſpective axes: for, by this contrivance the friction is transferred from the circumference of thoſe wheels to their pivots. And in like manner the friction may be ſtill farther diminiſhed by making the axes of thoſe wheels reſt upon other friction wheels that turn round with them. For the ſame reaſon friction balls or rollers have been placed within the naves of carriage wheels; and lately a Mr. Garnett had a patent for an improved manner of applying friction-wheels to any axis, as of carriages, blocks, pulleys, ſcale-beams, &c. in which the encloſed wheels or rollers are kept always at the ſame diſtance by connecting rods or bars.

(7.) Friction is diminiſhed by cauſing the ſurface of one kind of ſubſtance to run not upon the ſame kind of matter, but a ſurface of another material equally poliſhed. Thus, pivots of ſteel meet with leſs friction when they ſlide in grooves of copper, than when the grooves are of ſteel alſo.

(8.) As to friction in the mechanical powers: 1. The ſimple lever has no ſuch reſiſtance, unleſs the place of the fulcrum is changed during the operation. 2. In the wheel and axle, the friction on the axis is nearly as the weight upon it, the diameter of the axis, and the angular velocity. This ſort of friction, however, is very ſmall. 3. The friction of the pulley is very conſiderable when the ſheaves rub againſt the blocks. 4. There is alſo very great friction in the ſcrew: if the ſcrew has a ſquare thread it will raiſe a weight more eaſily than one with a triangular thread: but in moſt if not all ſcrews the friction is equal to the power. 5. In the inclined plane the friction varies according as the body rolls or ſlides; the friction in the latter caſe being far the greateſt. 6. In the wedge the friction is at leaſt equal to the power, ſince the wedge retains any poſition it is driven into.

30. Since cords and ropes are not perfectly flexible, it becomes neceſſary in eſtimating the advantages of pulleys, capſtans, &c. to make ſome allowance for this want of flexibility: in this caſe we may have recourſe to a theory which is far more ſatisfactory than any which has yet been invented with regard to friction, and which accords far better with experiment. The moſt uſeful formulæ may be deduced in a very ſmall compaſs. Thus, let $AC=CB=r$, the radius of a pulley (fig. 3. pl. I.) and two weights W and Q in equilibrio: if W ſhould prevail, it is obvious that the cord DQ becomes in the upper part bent ſo as to fit to the groove of the pulley, and in the lower part bent inwards ſo as to fall into the vertical *b* W: if the cord be tolerably flexible, the curving is pretty regular from B almoſt down to W: but if the cord be very rigid, BEW and ADQ are found to be nearly ſtraight lines, but neither of them vertical; the weight Q being found to hang vertically below ſome point as *a*, making C*a* greater than CA, and the weight W hanging below ſome point *b* where C*b* is leſs than CB. So that as the arm of the lever at which one of the forces act is become greater, and that of the other leſs than *r*, the condition of equilibrium is no longer $W=Q$.

When the cord is only moderately rigid, as in moſt practical caſes, the diſtance B*b* is always found ſo extremely ſmall that it may be ſafely neglected in the diſcuſſion; that is, we need in ſuch caſes pay no regard to the want of flexibility in the part BEW correſponding to the weight W which is ſuppoſed to prevail; but merely enquire into that of the part ADQ by which the other weight is ſuſpended. Hence, if we put $Aa=q$, the condition of equilibrium will be expreſſed thus:

$$W r=Q\ (r+q).$$

From this it reſults, that if $W-Q$ be the magnitude by which we ſhould augment the power, that it may be on the point of prevailing; and if we have regard to the ſtiffneſs of the cord, this magnitude will be $W-Q=Q\cdot\frac{q}{r}\cdot$ Conſequently, *to introduce the conſideration of the ſtiffneſs of the cord employed in a machine, we have only to ſuppoſe that the arm of the lever at which the reſiſtance acts is greater than it really is, by a determinate quantity* q.

It remains, then, to aſcertain this quantity q: in order to which, it may be obſerved that a cord reſiſts, on two accounts, the efforts which are made to bend it. The firſt is due to the tenſion of the cord, and is proportional to it, it will therefore be $=bQ$; the ſecond is due to its warping or twiſting, and we may repreſent by a the force employed to overcome it. Here a and b are, as is manifeſt, variable coefficients. Thus, for one and the ſame cord $a+bQ$ may repreſent the force required to bend it: but, if the cord be changed, the diameter d will be different, and we may conclude that, *cæteris paribus*, the force which muſt be employed will be proportional to a certain power n of d; for the force neceſſary to bend a cord will increaſe with its diameter: this power will decreaſe on the contrary with the radius r of the pulley; therefore $\frac{d^n}{r}\ (a+bQ)$ may repreſent the force neceſſary to overcome the ſtiffneſs of the cord; n being as yet an indeterminate quantity. This value being the augmentation which muſt be given to the force or weight W that it may be on the point of prevailing over the reſiſtance Q, muſt, from what is before ſhewn, be equal to $Q\,\frac{q}{r}$. Thus we have

$$d^n\ (a+bQ)=Q\,q,\ \text{or}\ q=\frac{d^n}{Q}\ (a+b\,Q)\quad .\ \ .\ \ .\quad \text{(A)}.$$

This equation, it is true, is only furniſhed by general conſiderations, and not by a rigorous inveſtigation: it contains, moreover, the unknown coefficients n, a, and b, varying for different cords. But there is a ſimple method of finding theſe coefficients, and of aſſuring ourſelves that the expreſſion is ſufficiently exact in practice.

31. Chooſe any cord, and after bending it along the groove of a pulley, as the cord QDABEW (fig. 3.), attach to it two equal weights, and augment one of them till it is juſt on the

point of prevailing ſo as to give motion to the ſyſtem, marking the difference of the weights. Make a ſimilar experiment four times, taking as many different values of W and of Q, alſo of r: ſo ſhall there be obtained four values of $W-Q$, that is to ſay, of $\frac{dn}{r}(a+bQ)$, which will furniſh four equations. Putting e, f, g, h, theſe values, and denoting by r, r', r'', r''', the ſeveral radii of the pullies, and Q, Q', Q'', Q''', the weights employed in their turns, we ſhall have

$$e=\frac{dn}{r}(a+bQ) \quad . \quad . \quad . \quad f=\frac{dn}{r'}(a+bQ')$$

$$g=\frac{dn}{r''}(a+bQ'') \quad . \quad . \quad . \quad h=\frac{dn}{r'''}(a+bQ''')$$

Of theſe equations the three firſt ſerve to diſcover the values of n, a, and b; and the laſt enables us to aſſure ourſelves whether the formula (A) has the accuracy we wiſh.

32. As to experiments on the rigidity of ropes and cords, we know none of any great importance and extent beſides thoſe of M. Coulumb. Theſe experiments were made with two kinds of apparatus, one contrived by M. Amontons, the other by M. Coulumb himſelf: the experiments made by means of one inſtrument corroborated the reſults of thoſe made by the other: but we ſhall here merely deſcribe the experiments by means of M. Coulumb's apparatus, which we prefer becauſe it was contrived to aſcertain at the ſame time that kind of friction which is occaſioned by the rolling of cylinders upon horizontal planes.

The apparatus conſiſts of two treſſels of 6 feet in height, and ſufficiently ſolid and firm, on which there are laid two pieces of ſquared wood; upon theſe two pieces of wood are fixed two rulers of oak well planed, DD, D′ D′ (fig. 4. pl. I. nos. 1. 2.), and poliſhed with a little fiſh-ſkin: then two cylinders of lignum vitæ are procured, one of 6 inches diameter, the other of two inches; together with ſeveral cylinders of elm from 2 to 12 inches in diameter.

Theſe things prepared, in order firſt to find the friction of the rollers, they are laid horizontally upon the two rulers of oak, and croſſing their directions perpendicularly, as repreſented in fig. 4. no. 2. the rulers being in a perfectly horizontal poſition: then ſuſpend on each ſide of the roller in uſe a weight of 50lbs. with very fine and flexible packthread; or indeed by means of ſeveral ſuch threads diſtributed over the roller, and charged each with 50 lbs. on each ſide, produce upon the rulers any determinate preſſure; and aſcertain by the aid of little counter-weights ſuſpended alternately on the different ſides of the roller what will be the force neceſſary to give it a motion barely ſenſible.

The friction of the rollers being eſtimated by the preceding method, it will be eaſy to allow for it, when inſtead of the very flexible packthread, the cords or ropes of which the ſtiffneſs is to be determined are ſubſtituted. And this new determination will be made in the ſame manner as with reſpect to the naſcent friction by ſuſpending the little weights alternately on each ſide of the roller, ſo that they ſhall give it a motion juſt perceptible.

It is obvious to remark that this method of eſtimating the effects of the rigidity of cords will furniſh reſults directly applicable to the preceding formulæ: for the weights which produce the very ſmall motion in the cylinders will be preciſely equal to the augmentation of the reſiſtance ariſing from the ſtiffneſs of the cord, eſtimated in the direction of that portion of the cord to which the reſiſtance is applied that repreſents the uſeful effect of the machine.

33. We ſhall firſt exhibit the reſults of M. Coulumb's experiments, on the ſecond ſpecies of friction, produced by rollers of lignum vitæ of 6 and of 2 inches diameter.

Charge of the rollers, their weight being comprised.	Weights which produce an extremely slow motion, the diameter of the rollers being	
	6 inches	2 inches
100 lb.	0·6	1·6
500	3·0	9·4
1000	6·0	18·0

From this table M. Coulumb infers that the friction of cylinders which roll upon horizontal planes, is directly as the preſſures, and inverſely as the diameters of the rollers. He alſo found that greaſing the ſurfaces did not here cauſe any ſenſible diminution in the friction.

Note. The foot and the pound ſpoken of throughout theſe experiments are thoſe of the ancient Paris ſtandard: we have not reduced them to Engliſh meaſures, ſince the deductions founded upon the experiments does not render this neceſſary.

Rollers of elm produced a friction of about the $\frac{2}{5}$ greater than lignum vitæ. And under ſmall preſſures the friction was rather greater than would reſult from the law of friction being proportional to the preſſure.

34. We ſhall next preſent the reſults of M. Coulumb's experiments upon the rigidity of cords, and different rollers between 2 and 12 inches in diameter: the deduction for the friction is ſtated in the table, and a comparative column exhibits the rigidity deduced from the experiments made with the ap-

paratus of Amontons. The cords were of three kinds: No. 1, of 6 threads in a yarn, or 2 in a ſtrand, the circumference 12½ lines, and weight of a foot in length 4½ drams. No. 2, of 15 threads in a yarn, or 5 in a ſtrand, circumference 20 lines, weight of a foot in length 12½ drams. No. 3, of 30 threads in a yarn, or 10 in a ſtrand, circumference 28 lines, weight of a foot in length 24½ drams.

No. of experiments.	Cords used in the experiments.	Kinds of wood: diameter and weight of the rollers.	Weights hung on each side the roller in lbs.	Addition. weight to surmount friction of roller and stiffness of cords.	Total charge of the rulers which support the roller.	Friction of the roller.	Stiffness of the Cord.	
							Valued by Coulumb's apparatus.	Valued by Amontons' apparatus.
1	Cord No. 3. of 30 threads in a yarn.	Elm 12 inches diameter, weight 110 lbs.	100	5 lbs.	315	1·5	3·5	4·4
			300	11	721	3·6	7·4	10·4
			500	20	1130	5·6	14·4	16·4
2	Idem.	Elm 6 inches diameter, weight 25 lbs.	200	18	443			
3	Idem.	Guiacum 6 inches diameter, weight 50 lbs.	200	16	466	2·8	13·2	14·8
4	Idem.	Guiacum 2 inches diameter, weight 4½ lbs.	25	11	65½			
			200	52	456½			
5	Cord No. 2. of 15 threads in a yarn.	Guiacum 6 inches diameter, weight 50 lbs.	25	1¼	101¼			
			100	6	256			
			200	11	461	2·8	8·2	7·6
			500	24	1074	6·4	17·6	17·8
6	Cord No. 1. of 6 threads in a yarn.	Idem.	100	3	253			
			200	6	456	2·7	3·3	3·1

From this table it will be ſeen that the method of Amontons and that of Coulumb furniſh nearly the ſame reſults: M. Coulumb aſcribes the differences where greateſt to the circumſtance of the cords having been more uſed previous to their being taken for one kind of experiment than for the other.

35. M. Coulumb, before he commenced the experiments upon the friction of axes, cauſed the pulley to turn on its axis during ſuch a time and with ſuch a velocity as was neceſſary to

enable the ſurfaces in contact to acquire all the poliſh and glibneſs of which they were ſuſceptible. The chief object held in view in the experiments of which we now ſpeak was to determine the friction of the axes of machines in motion. M. Coulumb therefore cauſed the ſuſpended weights to run over a ſpace of 6 feet, and to meaſure ſeparately by half ſeconds the time employed to run over the firſt three feet, and that occupied in running over the laſt three feet. The following table contains the reſults of experiments on the friction of axes of iron in boxes of copper: the axis uſed was 19 lines in diameter, and had a play of 1¼ lines in the copper box, the pulley was 144 lines in diameter, and weighed 14 pounds.

No. of experiments.	Kind of cord used.	Kind of greasing.	Weight used to bend the cord over the pulley.	Weight hung on each side of the pulley.	Additional weight to move the pulley.	Motion of the weight suspended on each side of the pulley.	Pressure on the axis.	Friction reduc. to surface of axis.	Ratio of friction to the pressure.
1	Very flexible thread of 3 lines circumference.	Friction without greasing.	0·0	103	6	Slow and irregular.	226	42	0·186
2	Cord No. 1. of 6 threads in a yarn.	Idem.	1·5	200	10·5	Slow and irregular.	424	65	0·153
					13·5	The first 3 ft. fallen thro' in 6″, the last 3 in 3″.			
3	Idem.	Idem.	3·0	400	21	Slow but continual.	825	130	0·156
					28	The first 3 feet described in 5″·5, the last three in 2″·5.			
					39	First 3 ft. described in 3″, the last 3 in 1½″.			
4	Very flexible thread, of 2 lines circumference.	tallow.	0·0	100	2·5	Slow but continual.	216·5	17·5	0·081
					6	The first 3 feet described in 3″·5, the last 3 in 1″·5.			
5	Cord No. 1. of 6 threads in a yarn.	Idem.	1·5	200	6·5	Slow but continual.	420	36	0·086
					10·0	The first 3 feet, described in 3″·5, the last 3 in 1″·5.			
6	Idem.	Idem.	3·0	400	13	Slow and continual.	827	72	0·087
					18	The first 3 feet, described in 5″·5, the last 3 in 2″.			
					24	first 3 feet in 3″, last 3 feet in 2″.			

7	Thread of 2 lines in circumference.	Cart grease.	0·0	50	2·5	Slow and continual.	117	17·5	0·15
8	Idem.	Idem.	0·0	100	3·7	Idem.	218	26	0·119
9	Idem.	Idem.	0·0	150	5·7	Idem.	320	40	0·125
10	Cord No. 1. of 6 threads in a yarn.	Idem.	0·7	100	4·3 9	Slow and uncertain. first 3 feet in 3", last 3 feet in 1½".	218	26	0·119
11	Idem.	Idem.	1·5	200	8·5 14 20	Uncertain. first 3 feet in 4", last 3 feet in 2". all 6 feet in 3"·5.	422	50	0·118
12	Idem.	Idem.	3·0	400	17 22 28	Uncertain. first 3 feet in 6"·5, last 3 feet in 2"·5. first 3 feet in 4", last 3 feet in 1"·5.	831	101	0·121
13	....	The cart grease of prec. exp. wiped, the pores of the metal remained unctuous.	......	......	......	....	From 200 to 1200 lbs.	......	0·127
14	....	The surface fresh done with oil.	......	......	......	....	......	......	0·127 0·133
15	....	The greasing not renewed of a long time, though the machine had been much used.	......	......	......	....	......	......	0·133

The weights employed to bend the cord, and which are contained in the 4th column, were calculated from the tenſions expreſſed in the 5th column, by means of the formulæ already given, and the reſults of ſome previous experiments. Theſe weights being ſubtracted from thoſe of the 6th column, which put the ſyſtem in motion, leave the weights employed in overcoming the friction. Theſe latter weights acting at a diſtance from the centre of rotation equal to the ſum of the radii of the pulley and the cord; the friction which is exerted upon the axis, and which in the caſe of a very ſlow motion may be conſidered as making an equilibrium with thoſe weights, is therefore equal to the product of thoſe weights into the ratio of the ſum of the radii of the pulley and the cord, to the radius of the axis, which ratio is very nearly 7 to 1, when the weight is ſuſpended by a thin packthread, and nearly 7·2 to 1, when it is ſuſpended by the cord No. 1. From theſe conſiderations the 9th column was calculated. The weights compriſed in the 8th column are compoſed, 1. Of the weight of the pulley or cylinder; 2. Double the correſponding weight in the 5th column; 3. The weights contained in the 6th column; for the ſum of theſe evidently compoſe the preſſure upon the axis. Hence, to find the ratio of the friction to the preſſure, as expreſſed in the 10th column, it is only neceſſary to divide any number in the 9th column by the correſponding one in the 8th.

36. When it is proper to have regard to the velocity of the weight, to aſcertain the effort which ſurmounts the friction and the ſtiffneſs of the cord, we may obſerve at once that in this caſe the motion is nearly a uniformly accelerated motion, ſince the firſt 3 feet are deſcribed in a time about double that employed in running over the laſt 3 feet. It remains, therefore, to learn what part w' of the additional weight ſtated in the 6th column, which we call w, was employed in accelerating the motion of the ſuſpended weight; for the other part of the additional weight, viz. $w - w'$, is manifeſtly that which ſurmounts the friction and the ſtiffneſs of the cords. Now t being the time of the whole deſcent, the accelerating force which has place is equal to $\frac{2 \times 6}{t^2}$; and, naming W the total ſum of the weight hanging upon the pulley compriſing in it 7 pounds for the inertia of the pulley, which weighed 14 pounds, and g the accelerating force of gravity, the maſs put in motion will be $\frac{W}{g}$, and the product of that maſs by the accelerating force will be $\frac{2 \times 6 W}{g t^2}$; which being ſubtracted from the additional weight which put the pulley in mo-

tion, gives the quantity $w-w'$, or the part of the weight w employed to overcome the ſtiffneſs of the cord and the friction.

It appears from the 7th, 8th, 9th, 10th, 11th, and 12th experiments, that the friction of axes of iron in boxes or cheeks of copper is much leſs ſoftened by the cart-greaſe than by tallow.

37. M. Coulumb has likewiſe endeavoured to aſcertain the friction of axes of rotation made of the different kinds of wood which are commonly found in rotatory machines. To render the friction more ſenſible he uſed pulleys of 12 inches mounted upon axes of 3 inches; ſometimes the axes were immoveable, at others they moved, but in both caſes the friction was the ſame: the proper precautions were adopted to ſmoothen the ſurfaces in contact, and thence to avoid the uncertainty and irregularity which might otherwiſe have attended the reſults.

Kinds of wood uſed in the experiments.	Ratio of friction to preſſure.
Axis of holm-oak, box of lignum vitæ, coated with tallow	0·038
Ditto the coating wiped, the ſurface remaining oily .	0·06
Axis and box as before, but uſed ſeveral times without having the coating refreſhed	0·06 0·08
Axis of holm-oak, box of elm, coated with tallow . .	0·03
Ditto both axis and box wiped, ſurfaces remaining oily	0·05
Axis of boxtree, box of lignum vitæ, coated with tallow	0·043
Ditto the coating wiped, the ſurfaces remaining oily .	0·07
Axis of boxtree, box of elm	0·035
Ditto the coating wiped off	0·05
Axis of iron, box of lignum vitæ, the coating wiped off, and the pulley turned for ſome time . . .	0.05

The velocity does not appear to influence the friction in any ſenſible manner, except in the firſt inſtants of motion: and in every caſe the friction is leaſt, not when the ſurfaces are plaſtered over, but when they are merely oily.

38. The experiments on the ſtiffneſs of cords deſcribed (art. 34) were made in caſes of motions nearly inſenſible; but M. Coulumb enquired whether with a finite velocity the reſulting effect of the ſtiffneſs of the cord were augmented or diminiſhed. For this purpoſe he took a pulley and box of copper, and an axis of iron done over with tallow: the diameter of the pulley was 144 lines, and that of the axis 20½ lines; and the cord was one of 30 threads to a yarn, or No. 3. of which the ſtiffneſs with reſpect to inſenſible velocities was determined by ſome of the foregoing experiments. The enſuing table ſhews the reſults of the experiments: the weights were made to run over a diſtance of 6 feet, and the times of deſcribing the firſt three and the laſt three feet were meaſured by a half-ſecond pendulum.

No. of experiments.	Weight hung on each side the pulley.	Additional weight to move the pulley.	Part of wt. to overcome friction and rigidity.	Motion of the weights hung upon the pulley.	Pressure on the axis in ıs.	Weight acting at extremity of pulley, balancing the friction	Stiffness of the cord deduced from the weights which move the pulley.	Stiffness of the cord estimated from its tension and former experim^{ts}.
1	100lbs.	7·5 lbs.	7·5 lbs.	Slow and continued	221 lbs.	2·6lbs.	4·9 lbs.	4·0 lbs.
		12	7·6	first 3 feet in 3′ last 3 feet in 1½″				
		15	7·6	first 3 feet in 2″ last 3 in 1½″				
2	200	11	11	Slow and uncertain	425	4·9	6·1	6·6
		15	12·9	first 3 feet in 6″ last 3 in 3″				
		19	12·2	first 3 feet in 3½″ last 3 in 1½″				
3	400	20·5	20·5	Slow and uncertain	834	9·7	10·8	11·8
		24	19·9	first 3 feet in 6″ last 3 in 3″				
		31	17·6	first 3 feet in 3′ last 3 in 2″				
4	600	31·5	31.5	Doubtful and conti.	1235	14·5	17·0	17·0
		37	31·5	first 3 feet in 6″ last 3 in 3½″				

It appeared in the table (art. 34.) that to bend the cord no. 3. of 30 threads in a yarn, about a roller of 12 inches diameter, and with a tenſion of 500lbs, would require a weight of 14·4 lbs: of which weight the conſtant part due to the fabrication of the cord is about 1·4 lbs: this value may be retained; but it will be here proper to deduce the part due to the tenſion of the cord by the quintal to $\frac{1}{5}$ (14·4 − 1·4) = $\frac{1}{5}$ × 13 = 2·6lbs. From theſe data the laſt column to the right of the above table was computed.

39. To complete the object of the experiments it is neceſſary to have the ſtiffneſs of the cord without aſſerting any thing *à priori* on the values which had been previouſly found for ſuch rigidity. To this end M. Coulumb has eſtimated the friction of the axis from its charge and the experiments of art. 35; where it appeared that this friction was independent of its velocity and equal to 0·087 of the preſſure. This friction which is exerted at the ſurface of the axis being computed, and the radius of the axis being to the diſtance between the centre of rotation and the middle of the cord as 1 to 7·5, it will be eaſy to calculate the weight which acting in the vertical direction of the middle of the cord may be in equilibrium with the friction in each experiment; and theſe weights are contained in the ſeventh column. Subtracting theſe weights from

the additional weights contained in the third column, namely thoſe which put the pulley in motion, we have in the caſe of a very ſlow motion the values of the weights which juſt ſurmount the ſtiffneſs of the cord; theſe weights are compriſed in the 8th column, and differ but little from thoſe calculated immediately and contained in the 9th column.

40. Now to know if the greater or leſs velocity of the weight ſuſpended upon the pulley has any influence upon the reſiſtance due to the ſtiffneſs of the cord, we muſt in the caſe of the motion calculate what portion of the additional weight hung upon the pulley is employed in overcoming the friction and the rigidity of the cord. Here the formula of a preceding article has its application, $w' = \frac{2 \times 6W}{g t^2}$: for, the time occupied by the weight in deſcribing the laſt three feet being nearly the half of that employed in deſcribing the firſt three feet, the motion may be conſidered as uniformly accelerated, and the quantities $w - w'$, which reſult, and are contained in the 4th column, differ but little, as is manifeſt, from the weights employed to overcome the friction and the ſtiffneſs of the cords, in the caſe of an extremely ſlow motion. And, as it appeared from the preceding experiments that the friction was independent of the velocity, or that it oppoſed the ſame reſiſtance to the motion in the different trials for each experiment; it hence follows that the reſiſtance ariſing from the ſtiffneſs of the cord was likewiſe conſtant in the ſame trials, and *depended not upon the velocity, at leaſt in any ſuch ſenſible manner as to merit our regard in computing the powers of machines.*

41. The invariableneſs of the reſiſtance occaſioned by the ſtiffneſs of cords, under different velocity, appears alſo immediately from the reſults compriſed in the 5th column of the table, which, as before obſerved, proves that the motions were nearly uniformly accelerated. And from this property it follows, that there is always a conſtant part of the weight or power employed in ſurmounting the friction and the ſtiffneſs of the cords.

"Nevertheleſs," adds M. Coulumb, "it muſt be acknowledged, that it is not *ſtrictly* true, that the augmentation of velocity does not augment the reſiſtance due to the rigidity of cordage. This augmentation appears eſpecially perceptible when the cords are ſtretched with weights or by forces that are under 100 pounds. I have eſtimated, by many trials, that in ſuch caſes a velocity of 8 feet per ſecond would increaſe by nearly a pound the reſiſtance occaſioned by the ſtiffneſs of our cord of 30 threads in a yarn: but this augmentation of reſiſtance ſeems to be a conſtant quantity for the ſame degree of velocity, whatever the tenſion may be; in ſuch ſort that it ceaſes to be perceptible under great tenſions, and that there are but very few circumſtances in which it may not be neglected in practice: this augmentation with regard to the velocity appears, beſides, much greater in new than in old cords, and in tarred cords than in thoſe which are white or untarred."

42. M. Coulumb deduces from theſe experiments the following general concluſions:

(1.) That with reſpect to practice, in all rotatory machines the ratio of the preſſure to the friction may always be ſuppoſed conſtant, and that the influence of the velocity is too ſmall to need our regard.

(2.) That the reſiſtance which muſt be overcome to bend a cord over a roller or pulley is repreſented by a formula compoſed of two terms; the firſt is a conſtant quantity independent of the tenſion, and of the form $\frac{ad^n}{r}$ (art. 31.) where a is a conſtant quantity determined by experience, d^n is a power of the diameter d of the cord, and r the radius of the roller; the ſecond term is $\frac{bd^n}{r}Q$, where b is a conſtant quantity, d, n, and r, as before, and Q the tenſion of the cord. Thus the complete formula expreſſing the ſtiffneſs of the cord is $\frac{d^n}{r}(a+bQ)$. The power n varies according to the flexibility of the cord, but is uſually about 1·7 or 1·8, or the reſiſtance is *nearly* proportional to the ſquare of the diameter of the cord: when the cord is much uſed n decreaſes to 1·5 or even 1.4. The following is a ſummary of reſults.

		$\frac{d^n}{r}a$ lbs.	$\frac{d^n}{r}b.100$
White Cord,	of 30 threads in a yarn	=4.2	= 9·0
	–15	=1·2	= 5·1
	– 6	=0·2	= 2·2
Tarred Cord,	of 30 threads in a yarn	=6·6	=11·6
	–15	=2·0	= 5·6
	– 6	=0·4	= 2·4

43. Our knowledge of the nature of the friction of axes, and ſtiffneſs of cords, though confeſſedly very imperfect, may be introduced into the computation of the power of machines: this may be illuſtrated by an example of a capſtan or windlaſs, where the general formula for an equilibrium will be this:

$$PR=QR'+\frac{rQ}{\sqrt{1+\frac{1}{ff}}}+d^n\cdot(a+bQ)$$

where P repreſents the power, and the other letters as below, The weight to be elevated, is

$$Q = 1000 \text{ lbs.}$$

The radius of the axis or pivot, which is of iron, is

$$r = 2 \text{ inches.}$$

This axis turns in a box of copper: the radius of the cylinder about which the cord is rolled, is

$$R' = 10 \text{ inches.}$$

The arm of the capſtan, or the radius, or diſtance at which the men exert their force, is

$$R = 10 \text{ feet} = 120 \text{ inches.}$$

The pivots are ſuppoſed to have been plaſtered with tallow ſome time, and the inſtrument often uſed, till the ratio of the friction to the preſſure is reduced to that of experiment 15 in the table of article 35. whence we have that ratio, or

$$f = 0{\cdot}133, \text{ and } \sqrt{1+\tfrac{1}{ff}} = 7{\cdot}5851.$$

The cord is ſuppoſed tarred, and of 120 threads in a yarn, which will ſupport 12 or 14000 lbs. without breaking. Now a tarred cord of 30 threads in a yarn requires a conſtant effort equivalent to 6·6 lbs. to bend it about a roller of 2 inches radius, and an effort proportional to the tenſion, of 11·6 lbs. for a quintal, or 116 lbs. for 1000 lbs. Here the radius of the cylinder being 10 inches, we muſt, firſt ſuppoſing the cords equal, diminiſh theſe efforts in the ratio of 10 to 2, viz. make their ſum $= \frac{2}{10}(6{\cdot}6+116)$ for 1000 lbs., and $= \frac{2}{10}(6{\cdot}6+\overline{8\times116})$ for 8000. And as the cord is of 120 threads in a yarn inſtead of 30, we muſt increaſe the laſt reſult, in the ratio of 30 to 120, ſo ſhall we have $\frac{4}{1}\times\frac{1}{5}(6{\cdot}6+928) = 747{\cdot}7$ for the effort which will ſurmount the ſtiffneſs of the cord, that is

$$\frac{d^n}{R'}(a+bQ) = 747{\cdot}7.$$

And ſince $R' = 10$, we have $d^n(a+bQ) = 7477$.
Theſe values being ſubſtituted in the general formula it becomes

$$P\times120 = (8000\times10) + \frac{8000\times2}{7{\cdot}5851} + 7477.$$

$$\text{or, } P = 666{\cdot}6 + 17{\cdot}577 + 62{\cdot}3 = 746{\cdot}5 \text{ lbs.}$$

It will be neceſſary therefore to diſtribute at the extremities of the bars of the capſtan efforts whoſe ſum ſhall be equivalent to 746·5 lbs.: that is, if a man makes an effort balancing 25 lbs., 30 men will be required to move the weight of 8000 lbs. Had there been no friction and were the cords perfectly flexible, the force neceſſary would have been only $\frac{8000}{12}$ or 666·6, leſs than the other by almoſt 80 pounds, a difference which is more than equivalent to the force of three men. So that in this example the friction and rigidity of the cord, require an increaſe of between an 8th and a 9th of the whole power which would otherwiſe have been requiſite.

This, however, we wiſh to be received only as an approximation. The details which have been here entered into will, we truſt, be found of ſome utility in directing the practice, and may furniſh ſome hints to thoſe who have time and inclination to adopt other ſeries of well-conducted experiments; and thus ſupply theſe moſt important deſiderata in practical mechanics.

On the Energy of Firſt Movers.

44. The conſideration of the abſolute and relative forces of different kinds of firſt movers is of too great conſequence in the application of mechanics to be entirely omitted in this performance: we ſhall, therefore, preſent the reader with ſome obſervations and tables reſpecting the chief claſſes of powers uſed to drive machinery, viz. water, air, ſteam, gunpowder, and animal exertion.

Water is generally made to operate upon machines by means of its momentum when in motion: but it may alſo be uſed, and that as a very powerful mover, when acting by its preſſure merely. In the theory of hydroſtatics (art. 387.) we explained the principle of the hydroſtatical paradox, in which it is aſſerted that any quantity of water or other fluid may be made to ſupport any other quantity or any weight however great, and indeed to *raiſe* the greater weight until it reaches ſuch a height as enſures the equilibrium. Thus in the hydroſtatic bellows the weight of a few ounces of water is made to raiſe ſeveral hundred pounds. And in like manner Otto Guericke of Magdeburg made a child balance, and even overcome, the pull exerted by the emperor's ſix coach horſes, merely by ſucking the air from beneath a piſton. This great power depends upon the fundamental property of fluids, that *they preſs equally in all directions.* Mr. Bramah, an ironmonger in Piccadilly, has lately obtained a patent for a machine acting as a preſs on this principle of the *quaqua verſum* preſſure of fluids: A piſton of $\frac{1}{4}$ of an inch diameter forces water into a cylinder of 12 inches diameter, and by this intervention raiſes the piſton of the cylinder: ſo that a boy acting with a fourth part of his ſtrength on the ſmall piſton by means of a lever can raiſe about 94080 lbs. or 42 tons preſſing on the great piſton; the increaſe of power being as 1 to $4^2 \times 12^2$ or 1 to 2304. This contrivance will be more minutely explained under the article *Bramah's machine*, in the alphabetical part of this volume.

45. As to the effect of water in motion, it will manifeſtly depend upon the quantity of fluid and its velocity jointly. When the water runs through a notch or an orifice of a regular form ſituated in the bottom or ſide of a reſervoir, the quantity diſcharged in any given time may be determined by the rules laid down for thoſe purpoſes in vol. 1. Book IV. If s^2 be the area of any plane expoſed to the action of a current of water, and v the velocity per ſecond with which the fluid ſtrikes the plane, then will the force of the fluid be equivalent to the weight of a volume of water expreſſed by $\frac{v^2 s^2}{2g}$, where g repreſents $32\frac{1}{6}$ feet, on the ſuppoſition that the water ſtrikes the plane *directly*: but if the fluid ſtrike the plane obliquely and I repreſent the angle of incidence, the force will be equivalent to the weight of the column $\frac{v^2 s^2}{2g}$ ſin.^{2} I. Or, ſince a cubic foot of water weighs $62\frac{1}{2}$ lbs averd. if v and s be expreſſed in feet we ſhall have $\frac{62\frac{1}{2} v^2 s^2}{2g}$ ſin.^{2} I $=$ ·971502 ſin.^{2} I $v^2 s^2$ lbs. averd. for the equivalent weight, which becomes barely ·971502$v^2 s^2$ lbs. when the plane is directly oppoſed to the fluid.

46. In the determination of the velocity of the ſtream it will be neceſſary either to aſcertain the height h through which the water has fallen freely, as from the end of a ſpout, when $\sqrt{2gh}$, or nearly 8 h, will ſhew the velocity, h being in feet; or when the water iſſues through an orifice in the bottom or ſide of a reſervoir, to have recourſe to Chap. 1 and 2. Book IV. vol. I. before referred to. If the ſtream be ample without much fall, ſuch as muſt neceſſarily be applied to move an underſhot wheel by its impulſe, the power will be determinable from the velocity of the water and the quantity which paſſes through the ſection of its bed. Dr. Deſaguliers, in his Experimental Philoſophy, vol. II. pa. 419. gives the following eaſy method of aſcertaining theſe data: Obſerve a place where the banks of the river are ſteep and nearly parallel, ſo as to make a kind of trough, for the water to run through, and by taking the depth at various places in croſſing make a true ſection of the river. Stretch a ſtring at right angles over it, and at a ſmall diſtance another parallel to the firſt. Then take an apple, an orange, or other ſmall ball, juſt ſo much lighter than water as to ſwim in it, and throw it into the water above the ſtrings. Obſerve when it comes under the firſt ſtring, by means of a half ſecond pendulum, a ſtop watch, or any other proper inſtrument; and obſerve likewiſe when it arrives at the ſecond ſtring. By this means the velocity of the upper ſurface, which in practice may

generally be taken for that of the whole, will be obtained. And the ſection of the river at the ſecond ſtring muſt be aſcertained by taking various depths, as before. If this ſection be the ſame as the former, it may be taken for the mean ſection: if not, add both together, and take half the ſum for the mean ſection. Then the area of the mean ſection in ſquare feet being multiplied by the diſtance between the ſtrings in feet, will give the contents of the water in ſolid feet, which paſſed from one ſtring to the other during the time of obſervation; and this by the rule of three may be adapted to any other portion of time. Suppoſe, for example, the time were 12″, and the hourly expenditure of water were required, the proportion would be, as 12″ : 3600″ : : the number of cubic feet between the two ſtrings : the hourly expenditure in cubic feet. If the mere velocity be required with reference to any fixed interval of time, a ſimilar proportion will give it, only obſerving to take, inſtead of the ſolid content or capacity in the third term, the diſtance between the two ſtrings.

The operation may often be greatly abridged by taking notice of the arrival of the floating body oppoſite two ſtations on the ſhore, eſpecially when it is not convenient to ſtretch a ſtring acroſs. An arch of a bridge is a good ſtation for an experiment of this kind, becauſe it affords a very regular ſection and two fixed points of obſervation: and in ſome inſtances the ſea practice of heaving the log may be advantageous. Where a time-piece is not at hand, the obſerver may eaſily conſtruct a half-ſeconds or quarter-ſeconds pendulum: the former may be made by ſuſpending a ſmall round (not flat) button, or other ſpherical weight, by a thread looped over a pin of ſuch a length that the diſtance from the point of ſuſpenſion to the centre of the weight ſhall be 9·8 inches: the quarter-ſeconds pendulum muſt be a fourth of this length. If, by obſervations at ſeveral ſtations above and below any particular point of the river, the velocity does not appear to vary, the ſection of the river in all that ſpace may be conſidered as uniform; and it will not be neceſſary to determine more than one ſection by actual meaſurement.

47. The effect of underſhot and overſhot wheels has been very variouſly ſtated by different authors; the moſt valuable and correct obſervations are thoſe of Mr. Smeaton, an abſtract of which was given in Chap. 4. Book IV. vol. I. The numerous practical remarks and experiments related in that chapter and the ſecond chapter of the ſame book, will render it unneceſſary for us now to dwell longer upon the effects of water as a mover of machinery.

48. Air is the next natural mover we propoſe to conſider. And this like water may be regarded either as at reſt, or in mo-

tion. The preſſure of the atmoſphere in a medium ſtate is equivalent to the weight of 14¾ or 15 lbs. averdupois on a ſquare inch; and this preſſure will ſupport, and, by means of a ſucking pump, *raiſe* water to the height of about 33 feet; it ſupports mercury in the barometer at the height of 28 to 32 inches.

The denſity of air is, at a medium, about 833 times leſs than that of water: if we take round numbers and reckon 800 to 1 for the ratio of the denſities, and put s^2 for the ſurface on which the wind ſtrikes, v for the velocity with which it moves, and I for the angle of incidence, then the force of the wind will be equal to the weight of a volume of water expreſſed by $\frac{1}{800} \cdot \frac{v^2 s^2}{4g} \text{ſin.}^2 I = {\cdot}0012144\, v^2 s^2 \text{ſin.}^2 I$ lbs. averdupois.

This formula, however, is only an approximation, and would lead to conſiderable errors when the velocities are great: on this ſubject we have treated pretty fully in art. 554, &c. Book V. vol. I. where the tables of Dr. Hutton, Mr. Rouſe, &c. are exhibited: the following is Mr. Rouſe's table of velocity and correſponding force in the form it was originally given by Mr. Smeaton; but the form in which it is thrown in art. 554 is more uſeful.

Velocity of the Wind.		Perpendicular force on one ſquare foot, in averdupois pounds.
Miles in one hour.	=feet in one ſecond.	
1	1·47	·005
2	2·93	·020
3	4·40	·044
4	5·87	·079
5	7·33	·123
10	14·67	·492
15	22·00	1·107
20	29·34	1·968
25	36·67	3·075
30	44·01	4·429
35	51·34	6·027
40	58·68	7·873
45	66·01	9·963
50	73·35	12·300
60	88·02	17·715
80	117·36	31·490
100	146·70	49·200

49. As it is not eaſy to obſerve the true velocity of the wind, and thence determine its force, ſeveral philoſophers have invented inſtruments called Anemometers or wind gages, by which the *force* of the wind may be aſcertained independent of its velocity. M. Bouguer contrived a very ſimple inſtrument for this purpoſe: it is a hollow tube AABB (fig. 5. pl. I.) in which a ſpiral ſpring CD is fixed, that may be more or leſs compreſſed by a rod FSD paſſing through a hole within the tube at AA. Having obſerved to what degree different forces or given weights are capable of compreſſing the ſpiral, put diviſions upon the rod in ſuch a manner that the mark obſerved at S in all poſitions of that rod ſhall indicate the weight requiſite to force the ſpring into the correſponding poſition CD. Afterwards join perpendicularly to this rod at F a plane ſurface EFE of a given area, either greater or leſs, as may be judged proper: then nothing more is neceſſary than to oppoſe this inſtrument to the wind, in order that it may ſtrike the ſurface in the directions VE, VE, parallel to that of the rod; and the mark at S will ſhew the weight to which the wind is equivalent. It will then be eaſy to reduce any obſerved force to a volume of water equivalent to it in energy; and ſo in all caſes aſcertain the magnitude of the force which the wind exerts.

50. The moſt uſual method of applying wind as a mover of machinery is in the conſtruction of windmills for different purpoſes, in which the wind produces its effect by impulſe upon the ſails. In theſe machines, therefore, whatever varieties there may be in the internal ſtructure, there are certain rules with regard to the poſition, ſhape, and magnitude of the ſails, which will bring them into the beſt ſtate for the action of the wind, and the production of uſeful effect. Theſe particulars have been conſidered much at large by Mr. Smeaton: for this purpoſe he conſtructed a machine of which a particular deſcription is given in the Philoſophical Tranſactions, vol. 51. By means of a determinate weight it carried round an axis with an horizontal arm, upon which were four ſmall moveable ſails. Thus the ſails met with a conſtant and equable blaſt of air; and as they moved round, a ſtring with a weight affixed to it was wound about their axis, and thus ſhowed what kind of ſize or conſtruction of ſails anſwered the purpoſe beſt. With this machine a great number of experiments were made; the reſults of which were as follow:

(1.) The ſails ſet at the angle with the axis, propoſed as the beſt by M. Parent and others, *viz.* 55°, was found to be the worſt proportion of any that was tried.

(2.) When the angle of the ſails with the axis was increaſed from 72° to 75°, the power was augmented in the proportion of 31 to 45; and this is the angle moſt commonly in uſe when the ſails are planes. See art. 547. vol. I.

(3.) Were nothing more requiſite than to cauſe the ſails to acquire a certain degree of velocity by the wind, the poſition recommended by M. Parent would be the beſt. But if the ſails are intended with given dimenſions to produce the greateſt effects poſſible in a given time, we muſt, if planes are made uſe of, confine our angle within the limits of 72 and 75 degrees.

(4.) The variation of a degree or two, when the angle is near the beſt, is but of little conſequence.

(5.) When the wind falls upon concave ſails it is an advantage to the power of the whole, though each part ſeparately taken ſhould not be diſpoſed of to the beſt advantage.

(6.) From ſeveral experiments on a large ſcale, Mr. Smeaton has found the following angles to anſwer as well as any. The radius is ſuppoſed to be divided into ſix parts; and $\frac{1}{6}$th, reckoning from the centre, is called 1, the extremity being denoted 6.

N°	Angle with that axis.	Angle with the plane of motion.
1	72°	18°
2	71	19
3	72	18 middle
4	74	16
5	77½	12½
6	83	7 extremity.

(7.) Having thus obtained the beſt method of *weathering* the ſails, *i. e.* the moſt advantageous manner in which they can be placed, our author's next care was to try what advantage could be derived from an increaſe of ſurface upon the ſame radius. The reſult was, that a broader ſail requires a larger angle; and when the ſail is broader at the extremity than near the centre, the figure is more advantageous than that of a parallelogram. The figure and proportion of enlarged ſails, which our author determines to be moſt advantageous on a large ſcale, is that where the extreme bar is one-third of the radius or whip (as the workmen call it), and is divided by the whip in the proportion of 3 to 5. The triangular or loading ſail is covered with board from the point downward of its height, the reſt as uſual with cloth. The angles above mentioned are likewiſe the moſt proper for enlarged ſails; it being found in practice, that the ſails ſhould rather be too little than too much expoſed to the direct action of the wind.

Some have imagined, that the more ſail the greater would be the power of the windmill, and have therefore propoſed to fill up the whole area; and by making each ſail a ſector of an ellipſis, according to M. Parent's method, to intercept the whole cylinder of wind, in order to produce the greateſt effect poſſible. From our author's experiments, however, it appeared, that when the ſurface of all the ſails exceeded ſeven-eights of the area, the effect was rather diminiſhed than augmented. Hence he concludes, that when the whole cylinder of wind is intercepted, it cannot then produce the greateſt effect for want of proper interſtices to eſcape.

"It is certainly deſirable (ſays Mr. Smeaton), that the ſails of windmills ſhould be as ſhort as poſſible; but it is equally deſirable, that the quantity of cloth ſhould be the leaſt that may be, to avoid damage by ſudden ſqualls of wind. The beſt ſtructure, therefore, for large mills, is that where the quantity of cloth is the greateſt in a given circle that can be: on this condition, that the effect holds out in proportion to the quantity of cloth; for otherwiſe the effect can be augmented in a given degree by a leſſer increaſe of cloth upon a larger radius than would be required if the cloth was increaſed upon the ſame radius."

(8.) The ratios between the velocities of windmill ſails unloaded, and when loaded to their maximum, turned out very different in different experiments; but the moſt common proportion was as 3 to 2. In general it happened that where the power was greateſt, whether by an enlargement of the ſurface of the ſails or an increaſed velocity of the wind, the ſecond term of the ratio was diminiſhed.

(9.) The ratios between the leaſt load that would ſtop the ſails and the maximum with which they would turn, were confined betwixt that of 10 to 8 and 10 to 9; being at a medium about 10 to 8.3, and 10 to 9, or about 6 to 5; though on the whole it appeared, that where the angle of the ſails or quantity of cloth was greateſt, the ſecond term of the ratio was leſs.

(10.) The velocity of windmill ſails, whether unloaded or loaded, ſo as to produce a maximum, is nearly as the velocity of the wind, their ſhape and poſition being the ſame. On this ſubject Mr. Ferguſon remarks, that it is almoſt incredible to think with what velocity the tips of the ſails move when acted upon by a moderate wind. He has ſeveral times counted the number of revolutions made by the ſails in 10 or 15 minutes; and, from the length of the arms from tip to tip, has computed, that if an hoop of the ſame ſize was to run upon plain ground with an equal velocity, it would go upwards of 30 miles in an hour.

(11.) The load at the maximum is nearly, but ſomewhat leſs than, as the ſquare of the velocity of the wind; the ſhape and poſition of the ſails being the ſame.

(12.) The effects of the ſame ſails at a maximum are nearly, but ſomewhat leſs than, as the cubes of the velocity of the wind.

(13.) The load of the ſame ſails at a maximum is nearly as the ſquares, and the effect as the cubes of their number of turns in a given time.

(14.) When ſails are loaded ſo as to produce a maximum at a given velocity, and the velocity of the wind increaſes, the load continuing the ſame; then the increaſe of effect, when the increaſe of the velocity of the wind is ſmall, will be nearly as the ſquares of theſe velocities: but when the velocity of the wind is double, the effects will be nearly as 10 to 27½; and when the velocities compared are more than double of that where the given load produces a maximum, the effects increaſe nearly in a ſimple ratio of the velocity of the wind. Hence our author concludes, that windmills, ſuch as the different ſpecies for draining water, &c. loſe much of their effect by acting againſt one invariable oppoſition.

(15.) In ſails of a ſimilar figure and poſition, the number of turns in a given time will be reciprocally as the radius or length of the ſail.

(16.) The load at a maximum that ſails of a ſimilar figure and poſition will overcome, at a given diſtance from the centre of motion, will be as the cube of the radius.

(17.) The effects of ſails of ſimilar poſition and figure are as the ſquare of the radius. Hence augmenting the length of the ſail without augmenting the quantity of cloth, does not increaſe the power; becauſe what is gained by length of the lever is loſt by the ſlowneſs of the motion. Hence alſo, if the ſails are increaſed in length, the breadth remaining the ſame the effect will be as the radius.

(18.) The velocity of the extremities of the Dutch ſails, as well as of the enlarged ſails, either unloaded or even when loaded to a maximum, is conſiderably greater than that of the wind itſelf. This appears plainly from the obſervations of Mr. Ferguſon, already related, concerning the velocity of ſails.

(19.) From many obſervations of the comparative effects of ſails of various kinds, Mr. Smeaton concludes, that the enlarged ſails are ſuperior to thoſe of the Dutch conſtruction.

(20.) He alſo makes ſeveral juſt remarks upon thoſe windmills which are acted upon by the direct impulſe of the wind againſt ſails fixed to a vertical ſhaft: his objections have, we believe, been juſtified in every inſtance by the inferior efficacy of theſe horizontal mills.

“ The diſadvantage of horizontal windmills (ſays he) does not conſiſt in this, that each ſail, when directly oppoſed to the wind, is capable of a leſs power than an oblique one of the ſame dimenſions; but that in an horizontal windmill little more than one ſail can be acting at once: whereas in the common windmill, all the four act together; and therefore, ſuppoſing each vane of an horizontal windmill to be of the ſame ſize with that of a vertical one, it is manifeſt that the power of a vertical mill will be four times as great as that of an horizontal one, let the number of vanes be what they will. This diſadvantage ariſes from the nature of the thing; but if we conſider the further diſadvantage that ariſes from the difficulty of getting the ſails back again againſt the winds, &c. we need not wonder if this kind of mill is in reality found to have not above one-eighth or one-tenth of the power of the common ſort; as has appeared in ſome attempts of this kind."

51. Another firſt mover, of whoſe effects it may be proper to give ſome account, is *fired gunpowder*. Theſe effects are too violent and ſudden to allow of their being applied to many practical purpoſes (the chief uſe of gunpowder being in the diſcharge of balls and ſhells from guns and mortars); but they are ſo prodigious and extraordinary, and are ſo important in the art of war, that it may be naturally expected we ſhould give ſome eſtimate of them in this place.

Now to underſtand the force of gunpowder it muſt be conſidered that whether it be fired in a vacuum or in air, it produces by its exploſion a permanently elaſtic fluid: and it appears from experiment that the elaſticity or preſſure of the fluid produced by this firing of gunpowder is, *cæteris paribus*, directly as its denſity.

To determine the elaſticity and quantity of this fluid, produced from the exploſion of a given quantity of gunpowder, Mr. Robins premiſes, that the elaſticity increaſes by heat, and diminiſhes by cold, in the ſame manner as that of the air; and that the denſity of this fluid, and conſequently its weight, is the ſame with the weight of an equal bulk of air, having the ſame elaſticity and the ſame temperature. From theſe principles, and from the experiments by which they are eſtabliſhed (for a detail of which we muſt refer to the book itſelf), he concludes that the fluid produced by the firing of gunpowder is nearly $\frac{3}{10}$ of the weight of the generating powder itſelf; and that the volume or bulk of this air or fluid, when expanded to the rarity of common atmoſpheric air, is about 244 times the bulk of the ſaid generating powder.—Count Saluce, in his Miſcel. Phil. Mathem. Soc. Priv. Taurin. p. 125, makes the proportion as 222 to 1; which he ſays agrees with the computation of Meſſrs. Hauksbee, Amontons, and Belidor.

Hence it appears, that any quantity of powder fired in any confined ſpace, which it adequately fills, exerts at the inſtant of its exploſion againſt the ſides of the veſſel containing it, and the bodies it impels before it, a force at leaſt 244 times greater than the elaſticity of common air, or, which is the ſame thing, than the preſſure of the atmoſphere; and this without conſidering the great addition ariſing from the violent degree of heat with which it is endued at that time; the quantity of which augmentation is the next head of Mr. Robins's enquiry. He determines that the elaſticity of the air is augmented in a proportion ſomewhat greater than that of 4 to 1, when heated to the extremeſt heat of red-hot iron; and ſuppoſing that the flame of fired gunpowder is not of a leſs degree of heat, increaſing the former number a little more than 4 times, makes nearly 1000; which ſhews that the elaſticity of the flame, at the moment of exploſion, is about 1000 times ſtronger than the elaſticity of common air, or than the preſſure of the atmoſphere. But, from the height of the barometer, it is known that the preſſure of the atmoſphere upon every ſquare inch is on a medium 14¾ lb; and therefore 1000 times this, or 14750 lb. is the force or preſſure of the flame of gunpowder, at the moment of exploſion, upon a ſquare inch, which is very nearly equivalent to 6 tons and a half.

This great force, however, diminiſhes as the fluid dilates itſelf, and in that proportion, viz. in proportion to the ſpace it occupies, it being only half the ſtrength when it occupies a double ſpace, one-third the ſtrength when triple the ſpace, and ſo on.

Mr. Robins further ſuppoſes the degree of heat above mentioned to be a kind of medium heat; but that in the caſe of large quantities of powder the heat will be higher, and in very ſmall quantities lower; and that therefore in the former caſe the force will be ſomewhat more, and in the latter ſomewhat leſs, than 1000 times the force of the atmoſphere.

He further found that the ſtrength of powder is the ſame in all variations in the denſity of the atmoſphere: but that the moiſture of the air has a great effect upon it; for the ſame quantity which in a dry ſeaſon would diſcharge a bullet with a velocity of 1700 feet in one ſecond, will not in damp weather give it a velocity of more than 12 or 1300 feet in a ſecond, or even leſs, if the powder be bad, and negligently kept. Robins's Tracts, vol. 1, p. 101, &c. Further, as there is a certain quantity of water which, when mixed with powder, will prevent its firing at all, it cannot be doubted but every degree of moiſture muſt abate the violence of the exploſion; and hence the effects of damp powder are not difficult to account for.

The velocity of expanſion of the flame of gunpowder, when fired in a piece of artillery, without either bullet or other body before it, is prodigiouſly great, viz. 7000 feet per ſecond, or upwards, as appears from the experiments of Mr. Robins. But M. Bernoulli and M. Euler ſuſpect it is ſtill much greater. And Dr. Hutton ſuſpects it may not be leſs, at the moment of exploſion, than 4 times as much.

It is this prodigious celerity of expanſion of the flame of fired gunpowder which is its peculiar excellence, and the circumſtance in which it ſo eminently ſurpaſſes all other inventions, either ancient or modern: for as to the momentum of theſe projectiles only, many of the warlike machines of the ancients produced this in a degree far ſurpaſſing that of our heavieſt cannon ſhot or ſhells; but the great celerity given to theſe bodies cannot be approached with facility by any other means than the exploſion of powder.

52. Since the important invention of the Steam-engine another ſpecies of firſt movers has come under the conſideration of the mechanical inveſtigator, namely, ſuch as ariſe from the volatiliſation of different fluids. Of theſe the one moſt commonly choſen is the STEAM raiſed from hot water, which is an elaſtic fluid, and which when raiſed with the ordinary heat of boiling water is almoſt 3000 times rarer than water, or more than 3½ times rarer than air, and then has its elaſticity equal to that of the common atmoſpheric air: by great heat it has been found that the ſteam may be expanded into 14000 times the ſpace of water, and then exerts a force of nearly 5 times the preſſure of the atmoſphere: and there is no reaſon to ſuppoſe this is the limit: indeed ſome accidents which have happened prove clearly that the elaſtic force of ſteam may at leaſt equal that of gunpowder.

The obſervations on the different degrees of temperature acquired by water in boiling, under different preſſures of the atmoſphere, and the formation of the vapour from water under the receiver of an air-pump, when with the common temperatures the preſſure is diminiſhed to a certain degree, ſhew clearly that the expanſive force of vapour or ſteam is different in the different temperatures, and that in general it increaſes in a variable ratio as the temperature is raiſed. Previous to deſcribing the method which has been adopted to meaſure the force of ſteam under different temperatures, it will be proper to deſcribe briefly the method by which the Chemiſts account for the production of aeriform fluids.

53. The term *Caloric* is uſed to denote the cauſe, whatever it may be, of heat, and of the phenomena which accompany heat: it is now almoſt univerſally admitted to be a highly elaſtic fluid. Every body is, according to its nature, capable of containing under a given volume a certain quantity of caloric,

either greater or leſs: this property was firſt obſerved by Dr. Black, and the Engliſh chemiſts deſignated it by the term *Capacity of a body to contain the matter of heat.* Profeſſor Wilcke and M. Lavoiſier firſt made uſe of the term *ſpecific caloric*, denoting by it the quantity of caloric reſpectively neceſſary to elevate to the ſame number of degrees the temperature of ſeveral bodies of equal weight.

Subſtances volatiliſed and reduced to *gas* or aeriform fluids, are nothing elſe than ordinary ſolid or fluid bodies which by ſome circumſtance are found ſuperabundantly combined with caloric, in ſuch a manner that the conſtituent particles of theſe bodies are ſeparated the one from the other, by a quantity of ambient caloric much more conſiderable than that which ſurrounds the ſame particles in the natural ſtate of the bodies. The extreme elaſticity of the caloric the effect of which is augmented by its condenſation, and the weakening of the reciprocal attraction or of the coheſion of the particles of the bodies (a weakening or diminution produced by the increaſed diſtance of thoſe particles) concur to diminiſh the denſity of the bodies in ſuch a manner that they become reduced to an aeriform ſtate.

54. As to the elaſticity of gaſeous fluids thus formed, it appears in great meaſure to be produced by the elaſticity of caloric itſelf, which, when bodies are reduced to the gaſeous ſtate, occupy a very great part of their volume. This eminent elaſticity of caloric tends continually to produce expanſion; on the other hand, this fluid, by a particular deſtination of nature, is more or leſs diſſeminated between the moleculæ of all bodies, in ſuch ſort that we may ſay with M. Lavoiſier that even in the ſolid ſtate theſe moleculæ do not touch, but, as it were, *ſwim* in the caloric at a certain diſtance from each other. There muſt, therefore, be a perpetual conteſt between the expanſive force of caloric which tends to diſſeminate the moleculæ, and the coheſive attraction of the moleculæ which tends to join them together. From the reciprocal intenſity of theſe two powers reſults the ſolid and liquid ſtates of bodies: thus, water only differs from ice by the greater or leſs condenſation of caloric, which permits more or leſs of the moleculæ of the liquid to yield to the effect of their attraction or reciprocal coheſion.

When ſubſtances paſs from the liquid to the aeriform ſtate, there is a third power to combine with the expanſive effort of caloric, and the aggregative or attractive effort of the moleculæ; namely, the preſſure of the atmoſphere, or of any elaſtic fluid whatever which compreſſes the fluid, and oppoſes itſelf to the ſeparation of its parts. This third power has a certain influence alſo upon the paſſage from the ſolid to the fluid ſtate, but it is moſt frequently (in this caſe) very ſmall, and even evaneſcent in compariſon of the reſiſtance ariſing from the mutual coheſion of the moleculæ. The contrary effect has place in the courſe of the paſſage from the liquid to the gaſeous or aeriform ſtate; the coheſion of the fluid moleculæ being extremely ſmall, the elaſticity of the caloric has ſcarcely any thing to ſurmount to produce volatiliſation beſides the preſſure of the atmoſphere, or gas which actually compreſſes it.

55. Hence it reſults that the ſame liquid under different preſſures ought to volatiliſe at different temperatures. M. Lavoiſier proved the truth of this reſult, by placing ether under the receiver of an air-pump and producing volatiliſation ſolely by taking off a part of the preſſure of the atmoſphere. See *Chymie, tome I. pa.* 9. And we know by many experiments of M. Deluc and others, that water boils the more ſpeedily as it is leſs preſſed by the weight of the atmoſphere.

Lavoiſier notices a curious conſequence of what has been here ſaid; which is, that if our planet revolved upon its axis with ſuch a velocity as to leſſen the preſſure of the atmoſphere, or if the temperature of the air were raiſed, then ſeveral fluids which we now ſee under a liquid ſtate would only exiſt in the aeriform ſtate; for example, if under the temperature of ſummer the preſſure of the atmoſphere were only equivalent to 20 or 24 inches of the barometrical tube, that preſſure would not retain ether in the fluid ſtate, it would be changed into gas; and the like would happen, if while the preſſure of the air was equivalent to 28 or 30 inches of the mercury the habitual temperature were 105 or 110 degrees on Fahrenheit's ſcale.

56. The principles which have been here exhibited are ſufficient for the underſtanding of all which relates to the action of water or other fluids reduced to vapour. Now, it has appeared from frequent experiments that water heated in common air volatiliſes at 80° of Reaumur's thermometer, or 212° of Fahrenheit's, the height of the barometer being 28 French, or 29·0 Engliſh inches: and ſpirits of wine under a like preſſure volatiliſes at between 63° and 64° of Reaumur, or nearly 175° of Fahrenheit. The expanſive force of the vapour muſt, therefore, in both theſe caſes, according to the principles juſt explained, be meaſured by a column of mercury of 28 French, or 29·9 Engliſh inches, in like manner as ſuch a column meaſures the preſſure of the atmoſphere, or the elaſticity of common air. And at any more elevated temperatures the elaſtic force of the vapour will ſurpaſs the preſſure of the atmoſphere by a quantity which has a certain relation with the exceſs of the temperature above thoſe juſt ſtated.

57. Till lately there was wanting on this important ſubject a

ſeries of exact and direct experiments by means of which, having given the temperature of the heated fluid, the expanſive force of the ſteam riſing from it might be known, and *vice verſa*. There was likewiſe wanting an analytical theorem expreſſing the relation between the temperature of the heated fluid and the preſſure with which the force of the ſteam was in equilibrio. Theſe deſiderata have, however, been lately ſupplied by M. Bettancourt, an ingenious Spaniſh philoſopher, after a method which we ſhall now conciſely explain.

58. M. Bettancourt's apparatus conſiſts of a copper veſſel or boiler, with its cover firmly ſoldered on: this cover has three orifices which cloſe up with ſcrews: at the firſt the water or other fluid is put in and out; through the ſecond paſſes the ſtem of a thermometer which has the whole of its ſcale or graduations above the veſſel, and its ball within, where it is immerſed either in the fluid or in the ſteam according to the different circumſtances; through the third hole paſſes a tube, making a communication between the cavity of the boiler and one branch of an inverted ſyphon, which contains mercury, and acts as a barometer for meaſuring the preſſure of the elaſtic vapour within the boiler. In the ſide of the veſſel there is a fourth hole into which is inſerted a tube with a turncock, making a communication with the receiver of an air-pump, in order to extract the air from the boiler and to prevent its return.

The apparatus being prepared in good order, and diſtilled water introduced into the boiler at the firſt hole, and then ſtopped, as well as the end of the inverted ſyphon or barometer, M. Bettancourt ſurrounded the boiler with ice, to lower the temperature of the water to the freezing point, and then, having extracted all the air from the boiler by means of the air-pump, the difference between the columns of mercury in the two branches of the barometer ſhewed the meaſure of the elaſtic force of the vapour ariſing from the water in that temperature. Then lighting the fire below the boiler, he gradually raiſed the temperature of the water from 0 to 110° of Reaumur's thermometer, that is, from 32° to 279½° of Fahrenheit's thermometer; and for each degree of elevation in the temperature he obſerved the height of the mercurial column which meaſured the elaſticity or preſſure of the vapour.

Theſe experiments were repeated various times and with different quantities of water in the veſſel; their reſults were arranged in different columns for the ſake of compariſon, and it appeared that the preſſures for different temperatures agreed very nearly, however much the quantity of fluid in the veſſel was varied. It was alſo ſeen that the increaſe in the expanſive force of the vapour is at firſt very ſlow; but increaſes gradually unto the higher temperatures, where the increaſe becomes very rapid, as will be obvious from an examination of the tables in ſome of the following pages.

59. To expreſs the relation between the degrees of temperature of the vapour and its elaſtic force, this philoſopher employs a method ſuggeſted by M. Prony, which conſiſts in imagining the heights of the columns of mercury meaſuring the expanſive force to repreſent the ordinates of a curve, and the degrees of heat the correſponding abſciſſæ of that curve; making the ordinates equal to the ſum of ſeveral logarithmic ones which contain two indeterminates, and aſcertaining theſe quantities in ſuch manner that the curve may agree with a tolerable number of obſervations taken throughout the whole extent of the change of temperature, from the loweſt to the higheſt extreme of the experiments. Then a formula or equation to a curve is inveſtigated, and when the curve correſponding to that equation is conſtructed, if it coincide (with the exception of a few trifling anomalies) with the curve conſtructed by the reſults of the experiments, the formula may be looked upon as correct, and furniſhing a true analytical repreſentation of the phenomena. This was done by M. Bettancourt; and the curve conſtructed from his equation has a point of inflexion at about the 102° of Reaumur, as it ought to have, becauſe the ſecond differences of the barometrical meaſures of the elaſtic force became negative at that temperature.

60. In a ſimilar manner M. Bettancourt made experiments on the ſtrength of the vapour from alcohol or ſpirit of wine; conſtructing the curve and deducing the requiſite analytical formula. This curve had likewiſe a point of inflexion at about 88° of Reaumur, the ſecond differences in the table of barometrical meaſures becoming then negative. From a compariſon of the experiments on the vapour of water with thoſe on the vapour of alcohol, a remarkable concluſion was derived: for it appeared that, after the firſt 20° of Reaumur, the ſtrength of the vapour of ſpirit of wine was to that of the vapour of water, nearly in the ſame conſtant ratio of 23 to 10, or 7 to 3, for any one and the ſame degree of heat. Thus, at the temperature of 40° of Reaumur, the ſtrength of the ſteam of water is meaſured by 2·9711 Paris inches in the barometer, and that of vapour of alcohol by 6·9770, the latter being about $2\frac{1}{3}$ times the former.

61. The equations to the curve of temperature and preſſure, denoting the relation between the abſciſſæ and ordinates, or between the temperature and the elaſticity of the vapour, as given by M. Bettancourt, were of the following form.

1. For water, $y = e^{\mu+\lambda x} - e^{\mu'+\lambda' x} - e^{\sigma x-\varrho} + e^{\sigma' x-\varrho'}$.

2. —— alcohol, $y = e^{\mu+\lambda x} + e^{\mu'+\lambda' x} - e^{\sigma x-\varrho} + e^{\sigma' x-\varrho'} - A$.

Where y repreſents the height of the column of mercury which meaſures the expanſive force, x the correſponding degrees of Reaumur's thermometer, and the other letters certain values which are aſſigned to them in the inveſtigation.

62. But M. Prony, in the 2d volume of his *Architecture Hydraulique*, has thrown theſe equations into a rather more convenient form, though analogous to thoſe of Bettancourt. His formula for the vapour of water is this,

$$y = \mu_{,}\varrho_{,}^{x} + \mu_{,,}\varrho_{,,}^{x} + \mu_{,,,}\varrho_{,,,}^{x} + \mu_{iv}\varrho_{iv}^{x}.$$

The method which he followed conſiſted in ſatisfying the reſults between 0° and 80°, by means of the two firſt terms, and to interpolate by means of the other two, the differences between the obſerved values, and thoſe computed by the two firſt terms, from 80° up to 110°. In this manner he ſucceeded to expreſs ſo exactly the obſervations in their whole extent, that the curves of the calculus and the experiments were only diſtinguiſhable the one from the other by ſuch little anomalies, as were manifeſtly the effect of ſome trifling though inevitable errors in the obſervations, and in the graduations of the ſcales in the apparatus. He afterwards employed an equation of three terms, giving to the different coefficients the following values:

$\varrho_{,} = 1{\cdot}172805$ . . . . log. $\varrho_{,} = 0{\cdot}0692259$
$\varrho_{,,} = 1{\cdot}047773$ . . . . log. $\varrho_{,,} = 0{\cdot}0202661$
$\varrho_{,,,} = 1{\cdot}028189$ . . . . log. $\varrho_{,,,} = 0{\cdot}0120736$
$\mu_{,} = -0{\cdot}000000724604 07$ . . . . . log. $\mu_{,} = \bar{7}{\cdot}8601007$
$\mu_{,,} = +0{\cdot}8648188803$ . . . . log. $\mu_{,,} = \bar{1}{\cdot}9369271$
$\mu_{,,,} = -0{\cdot}8648181057$ . . . . log. $\mu_{,,,} = \bar{1}{\cdot}9369248$

Subſtituting theſe ſeveral values in the equation

$$y = \mu_{,}\varrho_{,}^{x} + \mu_{,,}\varrho_{,,}^{x} + \mu_{,,,}\varrho_{,,,}^{x},$$

it ſatisfies not only the numbers employed in its formation, but all the intermediate obſervations, as may be concluded from the following table, which exhibits to every 10 degrees of Reaumur's thermometer the barometrical reſults both of obſervation and the calculus.

Tempe-rature.	Preſſures given by		Ano-malies.
	Experim.	Calculus.	
0	0·00 in.	0·00 in.	0·00 in.
10	0·15	0·24	+0·09
20	0·65	0·69	+0·04
30	1·52	1·51	−0·01
40	2·92	2·95	+0·03
50	5·35	5·42	+0·07
60	9·95	9·62	−0·33
70	16·90	16·57	−0·33
80	28·00	27·92	−0·08
90	46·40	45·87	−0·53
100	71·80	71·94	+0·14
110	98·00	98·36	+0·36

The anomalies are generally much more minute than in the formulæ of four terms: we may therefore regard the equation juſt preceding the table, which is more ſimple than that of Bettancourt, as repreſenting the phenomena and meaſuring the effects of the expanſive force of the ſteam of water with all deſirable accuracy. M. Prony remarks, that the ſmallneſs of the coefficient $\mu_{,}$ will allow the term $\mu_{,}\rho_{,}^{x}$ to be neglected in reckoning between 0° and 80°; and thus from the temperature of ice up to that of boiling water, the equation of two terms alone will ſuffice, that is to ſay . . . . $y=\mu_{,,}\rho_{,,}^{x}+\mu_{,,,}\rho_{,,,}^{x}$.

63. M. Prony's equation for the vapour of alcohol compriſes 5 terms originally: but in moſt caſes three of thoſe terms will give reſults ſufficiently accurate. The numeral values of the coefficients are as below:

$\rho_{,} = 1{\cdot}11424$ . . . . log. $\rho_{,} = 0{\cdot}04697771$
$\rho_{,,} = 1{\cdot}05714$ . . . . log. $\rho_{,,} = 0{\cdot}02413079$
$\rho_{,,,} = 0{\cdot}79943$ . . . . log. $\rho_{,,,} = \bar{1}{\cdot}9027776$
$\mu_{,} = -\ 0{\cdot}0021293$ . . . . . . log. $\mu_{,} = \bar{3}{\cdot}3282330$
$\mu_{,,} = +\ 0{\cdot}9116186$ . . . . . . log. $\mu_{,,} = \bar{1}{\cdot}9598132$
$\mu_{,,,} = +\ 0{\cdot}2097778$ . . . . . . log. $\mu_{,,,} = \bar{1}{\cdot}3217595$
$\mu_{iv} = -\ 1{\cdot}11192671$

Theſe numbers cauſe the experiments and calculus to coincide very nearly, when introduced into the equation

$$y=\mu_{,}\rho_{,}^{x}+\mu_{,,}\rho_{,,}^{x}+\mu_{,,,}\rho_{,,,}^{x}+\mu_{iv}.$$

The magnitude of the anomalies will be ſeen by inſpecting the following table.

Tempe-rature.	Preſſures given by		Ano-malies.
	Experim.	Calculus.	
0	0·00 in.	0·00 in.	0·00
10	0·47	0·45	−0·02
20	1·52	1·56	+0·04
30	3·49	3·54	+0·05
40	6·90	6·97	+0·07
50	13·05	12·93	- 0·12
60	23·65	23·05	−0·50
70	39·30	39·31	+0·01
80	63·80	64·35	+0·55
90	98·00	98·28	+0·28

Thus the formula for the vapour of ſpirit of wine is found as ſimple as that for the vapour of water, without ceaſing to repreſent the experiments with all deſirable exactneſs. But more than this, we may retrench one of the variable terms; for in the firſt degree $\mu_{\prime\prime\prime}\,\varrho_{\prime\prime\prime}{}^{x}$ has no greater value than 0·18, and when x is 2, 3, or any other poſitive value, this third term may be ſafely neglected. The equation therefore is reduced to

$$y=\mu_{\prime}\,\varrho_{\prime}^{x}+\mu_{\prime\prime}\,\varrho_{\prime\prime}{}^{x}+\mu_{iv};$$

a form much more ſimple than Bettancourt's original equation, and indeed more ſimple than Prony's improved equation for the vapour of water.

64. To ſave the trouble of inveſtigating the ſtrength of the vapour by theſe formula for every ſeparate caſe that may occur, we add a table (calculated from theſe principles) in which the ſtrength of the vapour both of water and of ſpirit of wine is ſhewn for every degree of Reaumur's thermometer up to 110°, or for every 2¼ degrees of Fahrenheit, from 32 to 280°: the ſtrengths are expreſſed, not in Engliſh or in French inches upon the barometer, but in terms whoſe unit is the medium preſſure of the atmoſphere, ſuppoſing that medium equivalent to 29·9 Engliſh, or 28 French inches of mercury. The preſſure upon a ſquare inch in pounds averdupois correſponding to any temperature may be found by multiplying the correſponding number taken from the table by 14·75: and the preſſure for any intermediate degree of Fahrenheit may be found pretty nearly, by proportioning, as is uſual in tables of Logarithms, &c.

Degrees of Thermometer.		Pressure in terms of Atmospheric Pressure.		Degrees of Thermometer.		Pressure in terms of Atmospheric Pressure.	
Reau.	Fahr.	Vapour of Water.	Vapour of Alcohol.	Reau.	Fahr.	Vapour of Water.	Vapour of Alcohol.
1	34¼	·00063	·00015	56	158	·27481	·65864
2	36½	·00124	·00074	57	160¼	·29076	·69671
3	38¾	·00192	·00171	58	162½	·30650	·73673
4	41	·00267	·00299	59	164¾	·32525	·77167
5	43¼	·00371	·00449	60	167	·34386	·82337
6	45½	·00433	·00641	61	169¼	·36345	·86946
7	47¾	·00539	·00849	62	171½	·38249	·91467
8	50	·00621	·01080	63	173¾	·40572	·96587
9	52¼	·00740	·01333	64	176	·42849	1·0231
10	54½	·00823	·01608	65	178¼	·45245	1·0795
11	56¾	·00971	·01832	66	180½	·47765	1·1385
12	59	·01085	·02163	67	182¾	·50414	1·2004
13	61¼	·01221	·02514	68	185	·53199	1·2652
14	63½	·01384	·02884	69	187¼	·56126	1·3330
15	65¾	·01521	·03276	70	189½	·59203	1·4038
16	68	·01706	·03689	71	191¾	·62436	1·4778
17	70¼	·01860	·04126	72	194	·65832	1·5552
18	72½	·02046	·04588	73	196¼	·69403	1·6359
19	74¾	·02244	·05076	74	198½	·74589	1·7199
20	77	·02454	·05591	75	200¾	·77096	1·8075
21	79¼	·02677	·06136	76	203	·81236	1·8985
22	81½	·02914	·06711	77	205¼	·85588	1·9932
23	83¾	·03165	·07319	78	207½	·90214	2·0855
24	86	·03432	·07961	79	209¾	·94957	2·1895
25	88¼	·03715	·08641	80	212	1·0000	2·2983
26	90½	·04014	·09358	81	214¼	1·0519	2·4074
27	92¾	·04331	·10116	82	216½	1·1064	2·5177
28	95	·04667	·10917	83	218¾	1·1634	2·6345
29	97¼	·05023	·11763	84	221	1·2232	2·7527
30	99½	·05364	·12657	85	223¼	1·2851	2·8739
31	101¾	·05833	·13603	86	225½	1·3500	2·9977
32	104	·06219	·14601	87	227¾	1·4177	3·1236
33	106¼	·06668	·15656	88	230	1·4872	3·2548
34	108½	·07136	·16771	89	232¼	1·5618	3·3806
35	110¾	·07634	·17949	90	234½	1·6382	3·5099
36	113	·08159	·19193	91	236¾	1·7176	
37	115¼	·08714	·20131	92	239	1·8003	
38	117½	·09302	·21898	93	241¼	1·8851	
39	119¾	·09921	·23366	94	243½	1·9733	
40	122	·10611	·24921	95	245¾	2·0643	
41	124¼	·11266	·26557	96	248	2·1579	
42	126½	·11934	·28289	97	250¼	2·2539	
43	128¾	·12762	·30120	98	252½	2·3527	
44	131	·13573	·32054	99	254¾	2·4533	
45	133¼	·14428	·34098	100	257	2·5534	
46	135½	·15329	·36256	101	259¼	2·6587	
47	137¾	·16279	·38538	102	261½	2·7628	
48	140	·17281	·40931	103	263¾	2·8667	
49	142¼	·18338	·43500	104	266	2·9735	
50	144½	·19447	·46193	105	268¼	3·0711	
51	146¾	·20609	·49036	106	270½	3·1691	
52	149	·21855	·52043	107	272¾	3·2631	
53	151¼	·23155	·55218	108	275	3·3505	
54	153½	·24524	·58571	109	277¼	3·4299	
55	155¾	·25228	·62117	110	279½	3·5127	

Several curious and in ſome reſpects uſeful conſequences might be deduced from theſe experiments and theorems. M. Bettancourt ſhews for inſtance, that the effect of ſteam engines muſt, in general, be greater in winter than in ſummer, owing to the different degrees of temperature in the water of injection. And from the greatly ſuperior ſtrength of the vapour of ſpirit of wine over that of water, he argues that, by trying other fluids, ſome may be found, not very expenſive, whoſe vapour may be ſo much ſtronger than that of water, with the ſame degree of heat, that it may be ſubſtituted inſtead of water in the boilers of ſteam engines, to the great ſaving in the expence of fuel: nay, he even aſſerts, that ſpirit of wine itſelf might thus be employed in a machine of a particular conſtruction, which, with the ſame quantity of fuel, and without any increaſe of expence in other things, ſhall produce an effect far ſuperior to what is obtained from the ſteam of water. Another uſe of theſe reſearches ſuggeſted by M. Bettancourt is, to meaſure the height of mountains by means of a thermometer immerſed in boiling water; which he thinks may be done with a preciſion equal, if not ſuperior, to that of the barometer. But this, being foreign to our preſent enquiries, cannot be entered upon here: a compariſon of the reſults of this method with ſome deduced from the more cuſtomary proceſs may be ſeen in Dr. Hutton's Dictionary, vol. II. pa. 756, to which ſuch as are deſirous of further information on this point are referred.

65. Our ingenious countryman Mr. Dalton, of Mancheſter, is of opinion that M. Bettancourt's deductions are not quite accurate. His chief error conſiſts in having aſſumed the force of vapour from water of 32° (Fahrenheit) to be nothing; which makes his numbers eſſentially wrong at that point and in all the lower parts of the ſcale: and in the higher part, or that which is above 212°, the force is determined too much; owing, as Mr. Dalton apprehends, to a quantity of air, which being diſengaged from the water by heat and mixing with the ſteam, increaſes the elaſticity.

Mr. Dalton's firſt experiments with ſpirit of wine led him to adopt the ſame concluſion as M. Bettancourt, with reſpect to the conſtant ratio between the force of the vapour from this ſpirit and that from water; and inferred the ſame with regard to the vapour from other fluids. But, on purſuing the ſubject, he concluded that this principle was not true, either with reſpect to ſpirit of wine or any other liquid. His experiments upon ſix different liquids agree in eſtabliſhing as a general law, "*That the variation of the force of vapour from all liquids is the* "*ſame for the ſame variation of temperature, reckoning from vapour* "*of any given force*: thus, aſſuming a force equal to thirty inches

" of mercury as the ſtandard, it being the force of vapour from " any liquid boiling in the open air, we find *aqueous* vapour " loſes half its force by a diminution of 30 degrees of tem- " perature: ſo does the vapour of any other liquid loſe half its " force by diminiſhing its temperature 30 degrees below that " in which it boils; and the like for any other increment or de- " crement of heat. This being the caſe, it becomes unneceſſary " to give diſtinct tables of the force of vapour from different " liquids, as one and the ſame table is ſufficient for all."

The experiments on which this concluſion reſts, are related in the fifth volume of the *Mancheſter Memoirs*: they may alſo be ſeen in the 6th volume of the New Series of *Mr. Nicholſon's Journal*. Mr. Dalton has calculated a table of the force of vapour of water from the temperature of 40° below zero of Fahrenheit, to 325° above it. From this table we have extracted the following; in which we have, as before, reduced the force to the medium preſſure of the atmoſphere for the meaſuring unit, that the ſmall differences in the reſults of the Engliſh and the Spaniſh philoſopher may be the more readily traced.

Temperature on Fahr.	Force of aqueous Vapour.	Temperature on Fahr.	Force of aqueous Vapour.
80°	·0333	212°	1·000
90	·0453	220	1·166
100	·0620	230	1·391
110	·0843	240	1·655
120	·1110	250	1·940
130	·1446	260	2·257
140	·1913	270	2·595
150	·2473	280	2·958
160	·3153	290	3·337
170	·4043	300	3·727
180	·5050	310	4·117
190	·6333	315	4·309
200	·7880	320	4·500
210	·9613	325	4·690

66. There remains for us to conſider another kind of mover of machinery, which is ANIMAL EXERTION, and which is of ſo fluctuating a nature that it is not eaſy to ſubject it to any eſtimate. Phyſical cauſes muſt affect both the magnitude and duration of the efforts either of man or beaſt, and beſides this,

the ſtrength of man is conſiderably influenced by his moral habits. The various combinations of theſe different cauſes have occaſioned a variety of eſtimates of animal labour to be advanced by different authors.

In the firſt volume of this work (art. 378.) we ſtated the average force of a man at reſt to be 70 lbs., and his utmoſt walking velocity when unloaded to be about 6 feet per ſecond; and we thence inferred that a man would produce the greateſt momentum when drawing 31$\frac{1}{9}$ lbs. along a horizontal plane with a velocity of 2 feet per ſecond. But this is not the moſt advantageous way of applying human ſtrength.

67. Dr. Deſaguliers aſſerts, that a man can raiſe of water or any other weight about 550 lbs., or one hogſhead (weight of the veſſel included), 10 feet high in a minute: this ſtatement, though he ſays it will hold good for 6 hours, appears from his own facts to be too high; and is certainly ſuch as could not be continued one day after another. Mr. Smeaton conſiders this work as the effort of haſte or diſtreſs; and reports that 6 good Engliſh labourers will be required to raiſe 21141 ſolid feet of ſea water to the height of four feet in four hours: in this caſe the men will raiſe a very little more than 6 cubic feet of freſh water each to the height of 10 feet in a minute. Now the hogſhead containing about 8$\frac{1}{2}$ cubic feet, Smeaton's allowance of work proves leſs than that of Deſaguliers in the ratio of 6 to 8$\frac{1}{2}$ or 3 to 4$\frac{1}{4}$. And as his good Engliſh labourers who can work at this rate are eſtimated by him to be equal to a double ſet of common men picked up at random, it ſeems proper to ſtate that, with the probabilities of voluntary interruption, and other incidents, a man's work for ſeveral ſucceſſive days ought not to be valued at more than half a hogſhead raiſed 10 feet high in a minute. Smeaton likewiſe ſtates, that 2 ordinary horſes will do the work in three hours and twenty minutes, which amounts to little more than two hogſheads and a half raiſed 10 feet high in a minute. So that, if theſe ſtatements be accurate, one horſe will do the work of five men.

68. Mr. Emerſon affirms, that a man of ordinary ſtrength turning a roller by the handle can act for a whole day againſt a reſiſtance equal to 30 pounds weight; and if he works 10 hours a day he will raiſe a weight of 30 lbs. through 3$\frac{1}{2}$ feet in a ſecond of time; or, if the weight be greater, he will raiſe it to a proportionally leſs height. If two men work at a windlaſs or roller, they can more eaſily draw up 70 lbs. than one man can 30 lbs.; provided the elbow of one of the handles be at right angles to that of the other. Men uſed to bear loads, ſuch as porters, will carry from 150 lbs. to 200 or 250 lbs. according to their ſtrength. A man cannot well draw more than 70 lbs.

or 80 lbs. horizontally: and he cannot thruſt with a greater force acting horizontally at the height of his ſhoulders than 27 or 30 lbs. But one of the moſt advantageous ways in which a man can exert his force is to ſit and pull towards him nearly horizontally, as in the action of rowing.

69. M. Coulumb communicated to the French National Inſtitute the reſults of various experiments on the quantity of action which men can afford by their daily work, according to the different manners in which they employ their ſtrength. In the firſt place he examined the quantity of action which men can produce when, during a day, they mount a ſet of ſteps or ſtairs, either with or without a burthen. He found that the quantity of action of a man who mounts without a burthen, having only his own body to raiſe, is double that of a man loaded with a weight of 68 kilogrammes, or 223 lbs. averdupois*, both continuing at work for a day. Hence it appears how much, with equal fatigue and time, the total or abſolute effort may obtain different values by varying the combinations of effort and velocity.

But the word *effect* here denotes the total quantity of labour employed to raiſe, not only the burthen, but the man himſelf; and, as Coulumb obſerves, what is of the greateſt importance to conſider is the *uſeful effect*, that is to ſay, the total effect, deducting the value which repreſents the transference of the weight of the man's body. This total effect is the greateſt poſſible when the man aſcends without a burthen; but the *uſeful* effect is then nothing: it is alſo nothing if the man be ſo much loaded as to be ſcarcely capable of moving: and conſequently there exiſts between theſe two limits a value of the load ſuch that the uſeful effect is a maximum. M. Coulumb ſuppoſes that the loſs of quantity of action is proportional to the load (an hypotheſis which experience confirms), whence he obtains an equation which, treated according to the rules of maxima and minima, gives 53 kilogrammes (173¼ lbs. averd.) for the weight with which the man ought to be loaded, in order to produce during one day, by aſcending ſtairs, the greateſt uſeful effect: the quantity of action which reſults from this determination has for its value 56 kilogrammes (183⅔ lbs. averd.) raiſed through one kilometre, or nearly 1094 yards. But this method of working is attended with a loſs of three-fourths of the total action of men, and conſequently coſts four times as much as work in which, after having mounted a ſet of ſteps without any burthen, the man ſhould ſuffer himſelf to fall by any means, ſo as to raiſe a weight nearly equal to that of his own body.

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* The kilogramme is = 22966 grs. = 3·28 lbs. averd.

From an examination of the work of men walking on a horizontal path, with or without a load, M. Coulumb concludes that the greateſt quantity of action takes place when the men walk being loaded; and is to that of men walking under a load of 58 kilogrammes (190$\frac{1}{4}$ lbs. averd.) nearly as 7 to 4. The weight which a man ought to carry in order to produce the greateſt *uſeful effect*, namely, that effect in which the quantity of action relative to the carrying his own weight is deducted from the total effect, is 50·4 kilogrammes, or 165·3 lbs. averdupois.

There is a particular caſe which always obtains with reſpect to burthens carried in towns, viz. that in which the men, after having carried their load, return unloaded for a new burthen. The weight they ſhould carry in this caſe, to produce the greateſt effect, is 61·25 kilogrammes (200·7 lbs. averd.). The quantity of uſeful action in this caſe compared with that of a man who walks freely and without a load is nearly as 1 to 5, or, in other words, he employs to pure loſs $\frac{4}{5}$ of his power. By cauſing a man to mount a ſet of ſteps freely and without burthen, his quantity of action is at leaſt double of what he affords in any other method of employing his ſtrength.

When men labour in cultivating the ground, the whole quantity afforded by one during a day amounts to 100 kilogrammes elevated to one kilometer, that is, 328 lbs. raiſed 1094 yards. M. Coulumb comparing this work with that of men employed to carry burthens up an aſcent of ſteps, or at the pile-engine, finds a loſs of about $\frac{1}{20}$ part only of the quantity of action which may be neglected in reſearches of this kind.

In eſtimating mean reſults we ſhould not determine from experiments of ſhort duration, nor ſhould we make any deductions from the exertions of men of more than ordinary ſtrength. The mean reſults have likewiſe a relation to climate. "I have cauſed," ſays M. Coulumb, "extenſive works to be executed by the troops at Martinico, where the thermometer (of Reaumur) is ſeldom lower than 20° (77° of Fahrenheit). I have executed works of the ſame kind by the troops in France: and I can affirm that under the fourteenth degree of latitude, where men are almoſt always covered with perſpiration, they are not capable of performing half the work they could perform in our climate*." *Bulletin de la Soc. Philomath*, No. 16.

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* In the preceding account of the effects of human exertion, ſince the profeſſed object was to ſtate the mean reſults of regular and uniform labour, we have taken no notice either of feats of extraordinary ſtrength, or of ſuch as were in *appearance* ſuch, while in reality they were the effect of contrivance and ſkill, and might have been performed by almoſt

70. Among quadrupeds the moſt uſeful as a firſt mover of machinery is the *horſe*. The ſtrength of this animal is pro-

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any men who had ſufficient knowledge of the ſubject to exert their ſtrength under ſimilar circumſtances. But as it may be expected that ſome notice ſhould be taken of ſuch matters, we ſhall throw into this note a few remarks which have formerly been made in reference to them.

M. de la Hire, in an *Examination of the Force of Men*, given in the Memoirs of the Academy of Sciences for 1699, ſays, “ There are men whoſe ſpirits flow ſo abundantly and ſo ſwiftly into their muſcles, that they exert three or four times more ſtrength than others do; and this ſeems to me to be the natural reaſon of the ſurpriſing ſtrength that we ſee in ſome men who carry and raiſe weights which two or three ordinary men can hardly ſuſtain, though theſe men be ſometimes but of a moderate ſtature, and rather appear weak than ſtrong. There was a man in this country a little while ago, who would carry a very large anvil, and of whom were reported ſeveral wonderful feats of ſtrength. But I ſaw another at Venice, who was but a lad, and did not ſeem able to carry above 40 or 50 lbs. with all poſſible advantages; yet this young fellow, ſtanding upon a table, raiſed from the earth, and ſuſtained off the ground, an aſs, by means of a broad girt, which, going under the creature's belly, was hung upon two hooks that were faſtened to a plat of ſmall cords coming down in treſſes from the hair on each ſide of the lad's head, which were in no great quantity. And all this great force *depended only upon the muſcles of the ſhoulders and thoſe of the loins*: for he ſtooped at firſt whilſt the hooks were faſtened to the girt, and then raiſed himſelf, and lifted up the aſs from the ground, bearing with his hands upon his knees. He raiſed alſo in the ſame manner other weights that ſeemed heavier, and uſed to ſay he did with more eaſe, becauſe the aſs kicked and ſtruggled when firſt lifted from the ground.”

Dr. Deſaguliers, in ſome annotations upon De la Hire's paper, ſays, “ What he attributes here to the *muſcles of the loins* was really performed by the extenſors of the legs; for the young man's ſtooping with his hands upon his knees was not with his body forwards and his knees ſtiff, but his body upright and his knees bent, ſo as to bring the two cords with which he lifted to be in the ſame plane with his ancles and the heads of his thigh bones; by which means the line of direction of the man and the whole weight came between the ſtrongeſt part of his two feet, which are the ſupports: then as he extended his legs he raiſed himſelf, without changing the line of direction. That this muſt have been the manner I am pretty well aſſured of, by not only obſerving thoſe that perform ſuch feats, but having often tried it myſelf. As for the muſcles of the loins, they are incapable of that ſtrain, being above 6 times weaker than the extenſors of the legs; at leaſt I found them ſo in myſelf.

“ About the year 1716, having the honour of ſhewing a great many experiments to his late majeſty king George the firſt, his majeſty was deſirous to know whether there was any fallacy in thoſe feats of ſtrength that had been ſhewn half a year before, by a man, who ſeemed by his make to be no ſtronger than other men: upon this I had a frame of wood made to ſtand in (and to reſt my hands upon), and with a girdle and chain lifted an iron cylinder made uſe of to roll the garden, ſuſtaining it eaſily when once it was up. Some noblemen and gentlemen who were preſent tried the experiment afterwards, and lifted the roller; ſome with more eaſe, and ſome with more difficulty, than I had done. This roller weighed 1900lbs. as the gardener told us. Afterwards I tried to lift 300 lbs. with my hands, (viz. two pails with 150 lbs. of quickſilver bably about ſix times that of a man. Deſaguliers ſtates the proportion as 5 to 1; coinciding with the deductions of Smea-

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in each), which I did indeed raiſe from the ground, but ſtrained my back ſo as to feel it three or four days: which ſhews that, in the ſame perſon, the muſcles of the loins (which exerted their force in this laſt experiment) are more then ſix times weaker than the extenſors of the legs: for I felt no inconveniency from raiſing the iron roller.”

During the time occupied in printing the ſecond volume of Dr. Deſaguliers's Philoſophy, a man of great natural ſtrength exhibited himſelf in London: of this man the doctor gives an account, from which the following is extracted:

“*Thomas Topham*, born in London, and now about 31 years of age, five feet ten inches high, with muſcles very hard and prominent, was brought up a carpenter, which trade he practiſed till within theſe ſix or ſeven years that he has ſhewed feats of ſtrength: but he is entirely ignorant of any art to make his ſtrength more ſurpriſing. Nay, ſometimes he does things which become more difficult by his diſadvantageous ſituation; attempting, and often doing, what he hears other ſtrong men have done, without making uſe of the ſame advantages.

“About ſix years ago he pulled againſt a horſe, ſitting upon the ground with his feet againſt two ſtumps driven into the ground, but without the advantages which might have been attained by placing himſelf in a proper ſituation; the horſe, however, was not able to move him, and he thought he was in the right poſture for drawing againſt a horſe; but when, in the ſame poſture, he attempted to draw againſt two horſes, he was pulled out of his place by being lifted up, and had one of his knees ſtruck againſt the ſtumps, which ſhattered it ſo, that, even to this day, the *patella*, or knee pan, is ſo looſe, that the ligaments of it ſeem either to be broken or quite relaxed, which has taken away moſt of the ſtrength of that leg.”

The exploits which Dr. Deſaguliers ſaw him perform were theſe:

“1. By the ſtrength of his fingers (only rubbed in coal aſhes to keep them from ſlipping,) he rolled up a very ſtrong and large pewter diſh.

“2. He broke ſeven or eight ſhort and ſtrong pieces of tobacco-pipe with the force of his middle finger, having laid them on the firſt and third finger.

“3. Having thruſt in under his garter the bowl of a ſtrong tobacco-pipe, his legs being bent, he broke it to pieces by the tendons of his hams, without altering the bending of his leg.

“4. He broke ſuch another bowl between his firſt and ſecond finger, by preſſing his fingers together ſideways.

“5. He lifted a table ſix feet long, which had half a hundred weight hanging at the end of it, with his teeth, and held it in an horizontal poſition for a conſiderable time. It is true the feet of the table reſted againſt his knees; but, as the length of the table was much greater than its height, that performance required a great ſtrength to be exerted by the muſcles of his loins, thoſe of his neck, the *maſſeter* and *temporal* (muſcles of the jaws), beſides a good ſet of teeth.

“6. He took an iron kitchen poker, about a yard long, and three inches in circumference, and, holding it in his right hand, he ſtruck upon his bare left arm, between the elbow and the wriſt, till he bent the poker nearly to a right angle.

“7. He took ſuch another poker, and holding the ends of it in his hands, and the middle againſt the back of his neck, he brought both ends of it together before him; and, what was yet more difficult, he pulled it ton, before mentioned. The French authors commonly reckon 7 men for 1 horſe. As a mean between theſe, we took, in

almoſt ſtraight again: becauſe the muſcles which ſeparate the arms horizontally from each other are not ſo ſtrong as thoſe that bring them together.

“ 8. He broke a rope of about two inches in circumference, which was in part wound about a cylinder of four inches diameter, having faſtened the other end of it to ſtraps that went over his ſhoulders. But he exerted more force to do this than any other of his feats, from his awkwardneſs in going about it; for the rope yielded and ſtretched as he ſtood upon the cylinder, ſo that when the extenſors of the legs and thighs had done their office in bringing his legs and thighs ſtraight, he was forced to raiſe his heels from their bearings, and uſe other muſcles that are weaker. But if the rope had been ſo fixed that the part to be broken had been ſhort, it would have been broken with four times leſs difficulty.

“ 9. I have ſeen him lift a rolling ſtone of about 800 lbs. with his hands only, ſtanding in a frame above it, and taking hold of a chain that was faſtened to it. By this, I reckon he may be almoſt as ſtrong again as thoſe who are generally reckoned the ſtrongeſt men, they generally lifting no more than 400 lbs. in that manner. The weakeſt men who are in health, and not too fat, lift about 125 lbs. having about half the ſtrength of the ſtrongeſt.

“ N. B. This ſort of compariſon is chiefly in relation to the muſcles of the loins; becauſe in doing this one muſt ſtoop forwards a little. We muſt alſo add the weight of the body to the weight lifted. So that if the weakeſt man's body weigh 150 lbs. that added to 125 lbs. makes the whole weight lifted by him to be 275 lbs. Then if the ſtronger man's body weighs alſo 150 lbs. the whole weight lifted by him will be 550 lbs. that is 400 lbs. and the 150 lbs. which his body weighs. *Topham* weighs about 200 lbs. which, added to the 800 lbs. that he lifts, makes 1000 lbs. But he ought to lift 900 lbs. beſides the weight of his body, to be as ſtrong again as a man of 150 lbs. weight who can lift 400 lbs.”

Again: “ About thirty years ago one *Joyce*, a Kentiſh man, famous for his great ſtrength, ſhewed ſeveral feats in London and the country, which ſo much ſurpriſed the ſpectators, that he was by moſt people called *the ſecond Sampſon*. But though the poſtures which he had learnt to put his body into, and found out by practice without any mechanical theory, were ſuch as would make a man of common ſtrength do ſuch feats as would appear ſurpriſing to every one who did not know the advantage of thoſe poſitions of the body; yet nobody then attempted to draw againſt horſes, or raiſe great weights, or to do any other thing in imitation of him: becauſe, as he was very ſtrong in the arms, and graſped thoſe that tried his ſtrength that way ſo hard that they were obliged immediately to deſire him to deſiſt, his other feats (wherein his manner of acting was chiefly owing to the mechanical advantage gained by the poſition of his body,) were entirely attributed to his extraordinary ſtrength.

“ But when he had been gone out of England, or had ceaſed to ſhew his performances for eight or ten years, men of ordinary ſtrength found out the way of making ſuch advantage of the ſame poſtures as *Joyce* had put himſelf into as to paſs for men of more than common ſtrength, by drawing againſt horſes, breaking ropes, lifting vaſt weights, &c. (though they could in none of the poſtures really perform ſo much as Joyce, yet they did enough to amaze and amuſe, and get a great deal of money), ſo that every two or three years we had a *new ſecond* Sampſon.

art. 378. vol. I. the proportion of 6 to 1, and ſtated the ſtrength of a horſe as equivalent to 420 lbs. at a dead pull. But the proportion is by no means conſtant, for it varies greatly according to the different kinds of work. Thus the worſt way of applying the ſtrength of a horſe is to make him carry a weight up a ſteep hill; while the organization of a man fits him very well for this kind of labour: hence, *three* men climbing up ſuch a hill with a weight of 100 lbs. each will proceed faſter than a horſe with a load of 300 lbs. This, we believe, was firſt obſerved by M. de la Hire.

We are not acquainted with any ſeries of experiments which have been made with a view of determining the weights horſes can carry when moving up ſloping roads, making given angles with the horizon: but, fortunately, this deficiency is not of much conſequence, becauſe the *carrying* of weights is far from the beſt manner of employing the ſtrength of a horſe. It is known, however, that, in general, a horſe loaded with a man and his equipage, weighing altogether about 2 cwt. may, without being forced, travel, in 7 or 8 hours, the diſtance of 43000 yards, or nearly 25 miles, upon a good road. When a horſe travels day after day without ceſſation, either the weight he carries or the diſtance paſſed over muſt undergo ſome diminution, as well as the time actually employed in travelling: but we do not pretend to aſſign a mean value in this place.

"About fifteen years ago a *German* of middle ſize, and but ordinary ſtrength, ſhewed himſelf at the *Blue Poſts*, in the Haymarket, and, by the contrivances above-mentioned, paſſed for a man of uncommon ſtrength, and got conſiderable ſums of money by the daily concourſe of ſpectators. After having ſeen him once, I gueſſed at his manner of impoſing upon the multitude; and being reſolved to be fully ſatisfied in the matter, I took four very curious perſons with me to ſee him again, viz. the lord marquis of Tullibardin, Dr. Alexander Stuart, Dr. Pringle, and a mechanical workman who uſed to aſſiſt me in my courſes of experiments. We placed ourſelves in ſuch manner round the operator, as to be able to obſerve nicely all that he did; and found it ſo practicable, that we performed ſeveral of his feats that evening by ourſelves, and afterwards I did the moſt of the reſt, as I had a frame to ſit in to draw, and another to ſtand in and lift great weights, together with a proper girdle and hooks. I likewiſe ſhewed ſome of the experiments before the Royal Society; and ever ſince at my experimental lectures I explain the reaſon of ſuch performances, and take any perſon of ordinary ſtrength that has a mind to try, who can eaſily do all that the German above-mentioned uſed to do, without any danger or extraordinary ſtraining, by making uſe of my apparatus for that purpoſe."

The Doctor then proceeds to explain the principles on which theſe achievements depended, and illuſtrates his poſitions by various diagrams. He likewiſe deſcribes ſome contrivances to determine the ſtrength which men exert in different ways; for an account of the chief of which, the reader may turn to the article STEELYARD, *to aſcertain the Strength of Men*, in a ſubſequent part of this volume.

71. In the Memoirs of the French Academy for 1703, are inſerted the comparative obſervations of M. Amontons, on the velocity of men and of horſes; in which he ſtates the velocity of a horſe loaded with a man and walking to be rather more than $5\frac{1}{4}$ feet per ſecond, or $3\frac{1}{2}$ miles per hour, and when going a moderate trot with the ſame weight to be about $8\frac{1}{2}$ feet per ſecond, or about 6 miles per hour. Theſe velocities, however, are ſomewhat leſs than what might have been taken for the mean velocities.

72. But the beſt way of applying the ſtrength of horſes is to make them draw weights in carriages, &c. To this kind of labour, therefore, the enquiries of experimentaliſts ſhould be directed. A horſe put into harneſs and making an effort to draw bends himſelf forward, inclines his legs, and brings his breaſt nearer to the earth; and this ſo much the more as the effort is the more conſiderable. So that when a horſe is employed in drawing, his effort will depend, in ſome meaſure, both upon his own weight and that which he carries on his back.

Indeed it is highly uſeful to load the back of a drawing horſe to a certain extent; though this, on a ſlight conſideration, might be thought to augment unneceſſarily the fatigue of the animal: but it muſt be conſidered that the maſs with which the horſe is charged vertically is added in part to the effort which he makes in the direction of traction, and thus diſpenſes with the neceſſity of his inclining ſo much forward as he muſt otherwiſe do; and may, therefore, under this point of view, relieve the draught more than to compenſate for the additional fatigue occaſioned by the vertical preſſure. Carmen, and waggoners in general, are well aware of this, and are commonly very careful to diſpoſe of the load in ſuch a manner that the ſhafts ſhall throw a due proportion of the weight on the back of the ſhaft horſe.

73. The beſt diſpoſition of the traces during the time a horſe is drawing is to be perpendicular to the poſition of the collar upon his breaſt and ſhoulders: when the horſe ſtands at eaſe, this poſition of the traces is rather inclined upwards from the direction of the road; but when he leans forward to draw the load, the traces ſhould then become nearly parallel to the plane over which the carriage is to be drawn; or, if he be employed in drawing a ſledge, or any thing without wheels, the inclination of the traces to the road, ſuppoſing it to be horizontal, ſhould (from what we obſerved when treating of friction) be about $18\frac{1}{2}$°.

74. From the preceding obſervations it will be eaſy in moſt caſes to adapt the ſize of the wheels to that of the animal which is to draw in the ſhafts, ſo that when he leans forward to his

work the traces may be nearly parallel to the road, whether that road be horizontal or not: always recollecting that, if there be any variation from the parallel poſition, it muſt be rather inclining upwards than downwards; as the former will ſomewhat diminiſh the friction, while the latter, inſtead of raiſing the wheels from any hollow into which they may fall, will tend to draw them down lower, and much increaſe the labour of the animal.

75. When ſeveral horſes are harneſſed one before another, ſo that they may all draw at the ſame load, and the ſlope on which they are drawing changes, as from DA to AB (fig. 6. pl. I.), the effort of the horſe which draws along the road AB is decompoſed into two parts, of which one tends to pull up the load, the other to pull *down* the horſe which is in the ſhafts and is drawing along the ſlope DA. This latter compoſant is always greater as the traces of the foremoſt horſe are the longer; and it may be worth while to find its values, and its augmentation with regard to an increaſe in the length of the traces. To this end let EA' be the height above AD of the breaſt of the horſe which draws in the ſhafts near the point A, and let ER and ER' be two different lengths of the traces; the breaſt of the horſe when harneſſed to either of theſe traces being at the ſame diſtance from the plane AB', that is, $BR = B'R' = EA'$. Take $EF = EF'$ to repreſent the effort of the horſe in the direction of the trace; draw $E q'$ parallel to DA, EQ perpendicular to BA produced, $E g$ parallel to AB, and $F q$, $F' q'$, perpendicular to $E q$. The effort which tends to pull the horſe down whoſe breaſt is at E is repreſented by $F q$, when the breaſt of the other horſe is at R, and by $F' q'$ when it is at R'; and $q E$, $q' E$ are the correſponding efforts tending to raiſe the load along the ſlope DA. Make $EA' = RB = R'B' = a$, $ER = \lambda$, $ER' = \lambda'$, angle $A'EQ = q E g =$ ſupplem. $DAB = s$, and $EF = EF' = \varphi$. Then, when the trace ER is uſed, the effort which tends to pull down the ſhaft horſe when he juſt reaches the ſummit of the ſlope will be $= \varphi \,.\, \text{ſin.}\, q EF = \varphi\ \text{ſin.}\ (q E g - FEg)$, and the effort tending to raiſe the load will be $= \varphi\ \text{coſin.}\ (q E g - FE g)$. In like manner, when the foremoſt horſe draws by the trace ER', the effort tending to pull down the ſhaft horſe will be repreſented by $\varphi\ \text{ſin.}\ (q Eg' - F'E g')$, and that which tends to draw up the carriage by $\varphi\ \text{coſin.}\ (q E g' - F'E g')$. Now we have ſin. $FE g = \frac{R g}{E R}$, and ſin. $F E g = \frac{R' g'}{ER'} = \frac{R g}{ER'}$. But $R g = BR - EQ = a - a\ \text{coſin.}\ s = a\ (1 - \text{coſin.}\ s)$. Recollecting, therefore, that the angles $FE g$, $F'E g$,

are always ſo ſmall that the arcs differ very little from the ſines, we have $FEg = \frac{a(1-\text{cosin. } s)}{\lambda}$, and $FEg' = \frac{a(1-\text{cosin.} s)}{\lambda'}$: theſe values being ſubſtituted in the preceding expreſſions, give

$$(1) \ldots Fq = \varphi \ \text{ſin.} \left(s - \frac{a(1-\text{cosin. } s)}{\lambda}\right).$$

$$(2) \ldots F'q' = \varphi \ \text{ſin.} \left(s - \frac{a(1-\text{cosin. } s)}{\lambda'}\right).$$

$$(3) \ldots Eq = \varphi \ \text{coſin.} \left(s - \frac{a(1-\text{cosin. } s)}{\lambda}\right).$$

$$(4) \ldots Eq' = \varphi \ \text{coſin.} \left(s - \frac{a(1-\text{oosin. } s.)}{\lambda'}\right).$$

Suppoſe, for example, that AB is horizontal, and that the aſcent DA is ſuch that for every ſix feet, as CN in a horizontal plane, the vertical riſe NA ſhall be one foot: this ſlope is too ſteep for any common road, but may be ſometimes met with in aſcents from ſtone quarries, &c. In this caſe the angle s will be nearly 9° 28′, which, expreſſed in decimal parts of the radius, gives $s = 0{\cdot}16522$, and coſin. $s = 0{\cdot}98638$. Let the effort $\varphi = 200$ lb., $a = 3\frac{1}{2}$ feet, $\lambda = 8$ feet, and $\lambda' = 12$ feet. Then ſhall we have,

$$(1) \ldots Fq = 200 \ \text{ſin.} \left(0{\cdot}16522 - \frac{3{\cdot}5\,(1-0{\cdot}98638)}{8}\right)$$
$$= 200 \ \text{ſin.}\ 9^\circ\, 7'\, 29'' = 31{\cdot}716 \text{ lbs.}$$

$$(2) \ldots F'q' = 200 \ \text{ſin.} \left(0{\cdot}16522 - \frac{3{\cdot}5\,(1-0{\cdot}98638)}{12}\right)$$
$$= 200 \ \text{ſin.}\ 9^\circ\, 14'\, 29'' = 32{\cdot}25 \text{ lbs.}$$

$$(3) \ldots Eq = 200 \ \text{coſin.}\ 9^\circ\, 7'\, 29'' = 177{\cdot}47 \text{ lbs.}$$

$$(4) \ldots Eq' = 200 \ \text{coſin.}\ 9^\circ\, 14'\, 29'' = 197{\cdot}404 \text{ lbs.}$$

Hence it appears, that the horſe whoſe breaſt is at E is pulled downwards by the other horſe, with a force equivalent to about 32 lbs: this weight is ſmall for a horſe that is not fatigued; but we ſhould conſider, that when drawing up a ſteep road the animal's ſtrength is much weakened, ſo that it may be obliged to yield to a very ſmall effort. A lengthening of four feet to a trace of eight feet will produce an augmentation of 32·25 − 31·716 = 0·534 lbs. in the effort which tends to pull the ſhaft horſe down, and a diminution of 197·47 − 197·404 = 0·066 lbs. in the effort which raiſes the load up the hill. Theſe quantities are not conſiderable; but it appeared deſirable to explain the method of aſcertaining their magnitude. And it may be added, that when a horſe pulls for only a ſhort time, as a few minutes, he will often exert a force equivalent to 500 or 600 lbs.: in which caſe, the tendency to pull down a ſhaft horſe riſing a hill would be thrice as much as we have ſtated it above: a force againſt which no horſe could ſtand in ſuch a diſadvantageous poſition.

76. When a horſe is made to move in a circular path, as is often practiſed in mills and other machines moved by horſes, it will be neceſſary to give the circle which the animal has to walk round, the greateſt diameter that will comport with the local and other conditions to which the motion muſt be ſubjected. It is obvious, indeed, that, ſince a rectilinear motion is the moſt eaſy for the horſe, the leſs the line in which he moves is curved, with the greater facility he will walk over it, and the leſs he need recline from a vertical poſition: and beſides this, with equal velocity the centrifugal force will be leſs in the greateſt circle, which will proportionally diminiſh the friction of the cylindrical part of the trunnions, and the labour of moving the machine. And, further, the greater the diameter of the horſe-walk, the nearer the chord of the circle in which the horſe draws is to coincidence with the tangent, which is the moſt advantageous poſition of the line of traction. On theſe accounts it is that, although a horſe *may* draw in a circular walk of 18 feet diameter, yet in general it is adviſeable that the diameter of ſuch a walk ſhould not be leſs than 25 or 30 feet; and in many inſtances 40 feet would be preferable to either.

77. It has been ſtated by Deſaguliers (vol. I. pa. 251) and ſome others, that a horſe employed daily in drawing nearly horizontally can move, during eight hours in the day, about 200 lbs. at the rate of 2½ miles per hour, or 3⅔ feet per ſecond. If the weight be augmented to about 240 or 250 lbs., the horſe cannot work more than ſix hours a day, and that with a leſs velocity. And, in both caſes, if he carry ſome weight, he will draw better than if he carried none (art. 72.) M. Sauveur eſtimates the mean effort of a horſe at 175 French, or 189 averd. pounds, with a velocity of rather more than three feet per ſecond: and this agrees very nearly with our deduction in art. 378. vol. I. But all theſe are probably too high to be continued for eight hours, day after day; for in our inveſtigation juſt referred to we aſſumed 10 feet per ſecond, as the utmoſt walking velocity of a horſe; a velocity which we conceive no horſe would be able to continue long. In another place Deſaguliers ſtates the mean work of a horſe as equivalent to the raiſing a hogſhead full of water (or 550 lbs.) 50 feet high in a minute. But Mr. Smeaton, to whoſe authority much is due, aſſerts, from a number of experiments, that the greateſt effect is the raiſing 550 lbs. forty feet high in a minute. And, from ſome experiments made by the Society for the Encourage-

ment of Arts, under the direction of their late able ſecretary, Mr. Samuel Moore, it was concluded, that a horſe moving at the rate of three miles an hour can exert a force of 80 lbs. Unluckily, we are not ſufficiently acquainted with the nature of the experiments and obſervations from which theſe deductions were made to inſtitute an accurate compariſon of their reſults. Neither of them ought to expreſs what a horſe can draw upon a carriage; becauſe in that caſe friction only is to be overcome (after the load is once put into motion); ſo that a middling horſe, well applied to a cart, will often draw much more than 1000 lbs. The proper eſtimate would be that which meaſures the weight which a horſe would draw up out of a well; the animal acting by a horizontal line of traction turned into the vertical direction by a ſimple pulley, or roller, whoſe friction ſhould be reduced as much as poſſible. It would, indeed, be far the beſt, in all the inſtances of experiments, to uſe no ſuch combinations of machinery as would make the velocity of the load or weight different from that of the animal: we could then readily compare the different reſults by means of the expreſſion $M \propto (W-V)^2$, or $M \propto (W-V)^{\frac{9}{5}}$ (art. 378, vol. I.), where V repreſents the velocity in feet per ſecond with which the animal moves the maſs M, and W his greateſt walking velocity, or that in which he can move no weight but his own. Thus might we obtain a mean eſtimate of the animal's ſtrength at any one velocity, and could thence infer his maximum of uſeful effort; namely, that when V is nearly $\frac{1}{3}$ W. As to the abſolute power of the animal, it might be inferred in any caſe of raiſing a weight with his own velocity, by means of the formula $\varphi=(M+H)\,V+M\,g\,t$, where M and V are as before, H the weight of the horſe, φ its power, $g=32\frac{1}{6}$ feet the meaſure of the force of gravity, and t the time in ſeconds during which the animal continues his uniform exertion.

78. It follows, from what has been ſaid, and from the conſideration of the ſtrengths of horſes variouſly employed, ſuch as waggon horſes, dray horſes, plough horſes, heavy horſes, light coach horſes, &c. that what is called "*horſe-power*" is of ſo fluctuating and indefinite a nature, that it is perfectly ridiculous to aſſume it as a common meaſure, by which the force of ſteam-engines and other machines ſhould be appreciated. In moſt of the deductions which have been hitherto made we apprehend there may be ſomething of temporary effort: and we think, on the whole, that about 70 lbs., at three miles an hour, or $4\frac{2}{5}$ feet per ſecond, may be a fair eſtimate for the regular work of ſtout London cart horſes; though we would

infer, with Mr. Nicholſon, "that the animal can double his "ſtrength for a ſhort time, ſuch as 10 minutes, without re- "ceiving any injury from the exertion."

Thus have we preſented a view of the moſt uſeful and correct information we have been able to collect, on the different energies of firſt movers: what is here done is not ſo ſatisfactory as might be wiſhed; but our knowledge on many of theſe points muſt remain imperfect, till freſh light is diffuſed over it by the diligent and able enquiries of future obſervers.

DESCRIPTIONS

OF

MACHINES:

ALPHABETICALLY ARRANGED.

AIR-PUMP is a machine by means of which the air may be exhauſted out of proper veſſels, ſo as to make what is popularly called a *vacuum*, but which is, in fact, only a very high degree of rarefaction.

The invention of this noble inſtrument, to which the preſent age is indebted for ſo many admirable diſcoveries, is aſcribed to *Otto de Guericke*, a conſul of Magdeburg, who exhibited his firſt public experiments with his pump before the emperor and the ſtates of Germany at the breaking up of the imperial diet at Ratiſbon, in the year 1654. Guericke, indifferent about the ſolitary poſſeſſion of an invention which afforded ſuch entertainment to the numerous perſons who, from time to time, witneſſed his experiments, gave a minute deſcription of all his pneumatic apparatus to Gaſper Schottus, profeſſor of mathematics at Wirtemberg, who publiſhed it, with the conſent of the inventor, with an account of ſome of its performances, firſt in 1657, in his *Mechanica Hydraulico-pneumatica*; and then, in 1664, in his *Technica Curioſa*. Guericke's own account was not publiſhed till 1672.

About the time of Guericke's invention the foundations of the Royal Society of London were laid. Boyle, Wren, Brounker, Wallis, and other learned men, held frequent meetings at Oxford, in which accounts were received and related of all important advances in the ſtudy of nature; and many experiments were exhibited. The reſearches of Galileo, Torricelli, and Paſcal, concerning the preſſure of the air, had greatly engaged their attention, and thus prepared them for the invention of Guericke. Mr. Boyle, in particular, as ſoon as he heard what had been accompliſhed by the philoſopher of Magdeburg, and before any deſcription of his machine had been publiſhed, ſet about the conſtruction of one, to anſwer the ſame purpoſes; and ſucceeded in the attempt: though he frankly acknowledges that it was but ſeldom, and with great difficulty, that he could produce an extreme degree of rarefaction; ſuch as it appeared, from the account of Schottus, was obtained by means of Guericke's machine.

Boyle's inſtrument was ſomewhat improved by Hawkſbee, and further by Martin; with ſome ſlight modifications to particular views, it ſtill remains the moſt approved form. The air-pump we deſcribed in art. 521. vol. I. is only ſo far varied from Hawkſbee's improvement of Boyle's original contrivance, as to render it more portable. The machine, in its primitive ſtate, is deſcribed in the article *Pneumatics*, *Engliſh Encyclopædia*; where, alſo, the ſucceſſive improvements of Smeaton, Cuthbertſon, &c. are deſcribed at large.

Many other ingenious attempts have been made, during the laſt ten or twelve years, to improve the mechaniſm of the air-pump; to deſcribe a fourth part of which would extend this article to more than its due length. Juſtice, however, to the authors of theſe improvements, as well as a deſire to gratify the reader, induces us to refer to Nicholſon's Journal, vols. I. and II. 4to. for deſcriptions of the air-pumps invented by meſſ. Prince, Sadler, Little, ſir G. Mackenzie, &c. and to Mr. Vince's Hydroſtatics for an account of the pump uſed by that gentleman in his lectures.

Notwithſtanding the many improvements which have ſucceſſively followed each other in the conſtruction of the air-pump, it was ſtill, however, deſirable that it ſhould be further ſimplified in its mechaniſm, while it poſſeſſed the ſame advantages as attended thoſe of more complicated ſtructure. Cuthbertſon, Haas, and ſome others, have ſo contrived their inſtruments, that their mechanical power, and not the preſſure of air, ſhould open the valves: but, although the air-pumps invented by theſe gentlemen are exceedingly ingenious, they are in ſome reſpects ſo complex, that it muſt be very difficult for many perſons who poſſeſs theſe inſtruments to clean them, or to keep them in proper order for experiments.

Mr. N. Mendleſſohn, a mathematical inſtrument-maker, of Surrey-ſtreet, Black-friars, having reflected upon the difficulties juſt alluded to, was led to the conſtruction of a more ſimple air-pump, which is capable of being put together in leſs than half an hour, whenever it is cleaned, and requires that operation very ſeldom. He has rejected the tube which, in common air-pumps, leads from the valves to the receiver, together with the cock that ſerves to ſhut this pipe: the receiver is placed immediately upon the valves, theſe being put on the top of the cylinders, which, conſequently, required the rackwork and pinion being underneath, and inverted the whole inſtrument. See the drawing, pl. IV. where AB and CD repreſent the two cylinders of glaſs ground and poliſhed inſide. E and F are the two valves that allow the cylinders to communicate with the receiver O through two very ſhort canals AB and CD (fig. 2: plate IV.) and the cock G. Two other valves that open into the atmoſphere are within the covers *i* and *k*, as may be ſeen in *fig.* 1, where *e* repreſents one of them. MN is the receiver-plate of glaſs ground flat; PQ a barometer-guage, upon the plan of the firſt Torricellian tube, as the eaſieſt to conſtruct and the moſt infallible in its effects. It will be found to be here quite out of the way, ſecure from being broke by accident, and the moſt in ſight. HK and IL are two braſs pillars that ſupport the whole. RSVW the uſual rackwork, having a double winch *l m*, which, upon trial, will be found preferable to a ſingle one.

It will now be neceſſary to ſhew how this pump acts, in which it will be ſufficient to explain the action of one cylinder, becauſe the other is in all parts like it. E is a conical metallic valve, from which a canal goes through the cock G up to the receiver, as is ſeen in fig. 1 and 2, where all the parts are marked with the ſame letters. ET is a ſteel rod going through a leather box in the piſton U. The top of this rod is fixed to the valve E, and its bottom part ſlides in a ſmall hole with an allowance of 0·1 inch up and downward, conſequently the valve E can move no further. When the piſton deſcends, it firſt opens the valve by puſhing the rod to the bottom of the hole. Then it ſlides down along the rod ET, and the air from the receiver has now free acceſs to the cylinder. When the piſton returns it lifts the rod ET, and thus ſhuts up the valve. Then the piſton ſlides again along the rod up to the top of the cylinder, condenſing the air above it, which air, by the leaſt condenſation, opens a valve *e*, fig. 2, and eſcapes freely into the atmoſphere. This laſt valve has neither ſpring nor additional weight to ſhut it, but ſhuts by its own weight (about a quarter of an ounce) as ſoon as the piſton is arrived to the top of the cylinder.

The cylinders are made of glaſs, *and the piſtons of tin, ſo well fitted as to be air-tight, without the interpoſition of any leathers.*

The friction of theſe two bodies is ſmall beyond expectation, a ſufficient proof that they will be durable. They poſſeſs the further advantage of being capable of ſtanding for even ſix months, after which time they will ſerve without being cleaned or repaired, becauſe they are not liable to be corroded by the oil which they contain, an inconvenience too general in braſs cylinders. After all, if the preſent pump ſhould want cleaning, it is an eaſy operation to take off the top piece *g h*, by unſcrewing the nuts H and I, when this piece, with all the apparatus upon it, will come off. Then each cylinder may very eaſily be ſlid off from the piſton, wiped out and replaced, after having greaſed it inſide with a little of the cleaneſt ſweet oil: the top is then to be put again in its place, and the two nuts H and I being ſcrewed upon it, the inſtrument is ready. Neither racks nor pinion need to be taken out of their places, the cylinders ſtanding above them.

The cock is conſtructed ſo, that, being in the ſituation repreſented in fig. 1, the communication is open between the cylinders, the receiver, and the barometer-guage, and, by a quarter of a revolution, the cylinders are excluded, the receiver and guage being ſtill left in communication. A little ſtopper in fig. 2, ground into the cock, being open, air is admitted to the receiver, if required.

The receiver-plate is of glaſs ground flat, as was mentioned before: this will be found preferable to braſs, becauſe cleaner, and never corroded by acids or water; it will beſides often prove very convenient in making electrical experiments in the vacuum.

The whole inſtrument is fixed upon a mahogany-table, which ſerves as a ſtand for it.

Mr. Mendelsſhon concludes his deſcription by obſerving that "neither the employing of glaſs cylinders, nor the method of opening the valves, is new; but, for aught he knows, this is the firſt inſtrument of the kind ever executed: and the idea of putting the valves at top, and thus ſimplifying the inſtrument, ſeems to have eſcaped the attention of the eminent artiſts, both here and abroad, as, to my beſt knowledge, it has never been done or deſcribed any where. The metallic piſtons, without leathering, muſt certainly add to the durability, and diminiſh the great labour that uſually attends working an air-pump." *Nicholſon's Journal, New Series, No.* 39.

Mr. Vream, who was Dr. Deſaguliers's operator for philoſophical machines, made ſuch an alteration in Hawkſbee's air-pump, as produced the alternate reciprocating motion of the piſtons, without turning the handle to and fro: while the handle turns conſtantly one way in its operation, a crank by means of two leading pieces, gives the wheel that moves the racks a motion of about two-thirds (or more when required) of its circumference, every time the crank goes round. The advantages which Mr. Vream thought would reſult from this alteration, he deſcribes in the following words: "I hope I have improved Mr. Hawkſbee's pump by a contrivance whereby in turning the winch quite round the *emboli*, or piſtons, are alternately raiſed and depreſſed; whereas in Mr. Hawkſbee's way, the moving of the hand backward and forward is not only more troubleſome, but ſhakes the pump; becauſe it is required to preſs the barrel hard againſt the bottom piece under the barrels, to diſcharge the water from the valves at every ſtroke. Beſides if the pump ſhould at any time happen to leak, when an experiment ſhould be made in haſte; you may exhauſt ſo faſt this way as to make your experiment without being at the trouble to pull the pump to pieces, in order to make it tight, except in ſuch caſes as require the recipient to be perfectly exhauſted."

Fig. 11. pl. III. will ſhew in what this improvement of Mr. Vream's conſiſts. The axis DB on which the crank A *a b* and handle BF turn, is perpendicular to the plane of the wheel WE which moves the racks S,T: two leaders N,N, of equal length, are hung by one end upon the crank A *a*, and by the other upon the two ends of a pin I which paſſes through the wheel at a ſuitable diſtance from the centre. While the crank is riſing the pin I is raiſed from its poſition in the figure to ſome higher point, as R, thus cauſing the wheel to turn upon its centre E, and raiſe the rack S, while it depreſſes the rack T: afterwards, while the crank is deſcending through the other half of its revolution, the pin is puſhed back again from R to I, the wheel E turns the contrary way, the rack T is raiſed, and S depreſſed. So the racks are alternately raiſed and depreſſed as the circular motion of the handle F carries round the crank A *a*. The radius *a b* of the crank muſt be rather leſs than the diſtance EI of the pin I from the centre of the wheel, in order to enſure the alternate motion of the piſtons: and the more extenſive the motion of theſe is required to be with reſpect to the motion of the crank, the more muſt the radius of the wheel EW exceed the diſtance EI.

This contrivance, however ingenious, has been ſeldom applied to air-pumps; probably becauſe there is a conſiderable variation of requiſite moving force in the different parts of the revolution of the crank; a variation which may produce jolts in the motion. But this inequality of force upon the crank, being occaſioned by the variable obliquity in the poſition of the leaders N,N, may be much reduced by making the diſtances *a b*, EI, as ſmall as can be conveniently, with reſpect to the length *a*I of the leaders.

ANEMOMETER. See art. 49. of the introductory part of this volume.

ATWOOD's MACHINE, the name which is now commonly applied to the ingenious apparatus invented by Mr. Atwood of Trinity college, Cambridge, to illuſtrate the doctrines of accelerated motion. This machine has been found to anſwer the purpoſe far more completely than any other; ſubjecting to experimental examination, the quantity of matter moved, the meaſure of the force which moves it, the ſpace deſcribed from quieſcence, the time of deſcription, and the velocity acquired. The theory of this inſtrument depends upon the principles exhibited in art. 267. vol. i. But we ſhall here give ſo much of the theory and deſcription as ſeems neceſſary to ſhew its nature and uſe, chiefly in the words of the ingenious inventor.

1. *Of the maſs moved.*—In order to obſerve the effects of the moving force, which is the object of any experiment, the interference of all other forces ſhould be prevented: the quantity of matter moved, therefore, conſidering it before any impelling force has been applied, ſhould be without weight; for although it be impoſſible to abſtract the natural gravity or weight from any ſubſtance whatever, yet the weight may be ſo counteracted as to be of no ſenſible effect in experiments. Thus in the inſtrument conſtructed to illuſtrate this ſubject experimentally, A, B, fig. 1. pl. V. repreſent two equal weights affixed to the extremities of a very fine and flexible ſilk line: this line is ſtretched over a wheel or fixed pulley *abcd*, moveable round an horizontal axis: the two weights A, B, being preciſely equal and acting againſt each other, remain in equilibrio; and when the leaſt weight is ſuperadded to either (ſetting aſide the effects of friction), it will preponderate. When AB are ſet in motion by the action of any weight *m*, the ſum $A+B+m$ would conſtitute the whole maſs moved, but for the inertia of the materials which muſt neceſſarily be uſed in the communication of motion: theſe materials conſiſt of, 1. The wheel *abcd*, over which the line ſuſtaining A and B paſſes. 2. The four friction-wheels, on which the axle of the wheel *abcd* reſts: the uſe of theſe wheels is to prevent the loſs of motion, which would be occaſioned by the friction of the axle if it revolved on an immoveable ſurface. 3. The line by which the bodies A and B are connected, ſo as when ſet in motion to move with equal velocities. The weight and inertia of the line are too ſmall to have ſenſible effect on the experiments; but the inertia of the other materials juſt mentioned conſtitute a conſiderable propor-

tion of the maſs moved, and muſt be taken into account. Since when A and B are put in motion, they muſt neceſſarily move with a velocity equal to that of the circumference of the wheel *abcd*, to which the line is applied; it follows, that if the whole maſs of the wheels were accumulated in this circumference, its inertia would be truly eſtimated by the quantity of matter moved; but ſince the parts of the wheels move with different velocities, their effects in reſiſting the communication of motion to A and B by their inertia will be different; thoſe parts which are furtheſt from the axis reſiſting more than thoſe which revolve nearer in a duplicate proportion of thoſe diſtances. If the figures of the wheels were regular, from knowing their weights and figures, the diſtances of their centres of gyration from their axes of motion would become known, and conſequently an equivalent weight, which being accumulated uniformly in the circumference *abcd*, would exert an inertia equal to that of the wheels in their conſtructed form. But as the figures are wholly irregular, recourſe muſt be had to experiment, to aſſign that equivalent quantity of matter, which being accumulated uniformly in the circumference of the wheel *abcd*, would reſiſt the communication of motion to A in the ſame manner as the wheels.

In order to aſcertain the inertia of the wheel *abcd*, with that of the friction-wheels, the weights AB being removed, the following experiment was made. A weight of thirty grains was affixed to a ſilk line (the weight of which was not ſo much as $\frac{1}{4}$th of a grain, and conſequently too inconſiderable to have ſenſible effect in the experiment); this line being wound about the wheel *abcd*, the weight 30 grains by deſcending from reſt communicated motion to the wheel, and by many trials was obſerved to deſcribe a ſpace of about 38½ inches in 3 ſeconds. From theſe data the equivalent maſs or inertia of the wheels will be known from this rule:

Let a weight P (fig. 2.) be applied to communicate motion to a ſyſtem of bodies by means of a very ſlender and flexible line going round the wheel SLDIM, through the centre of which the axis paſſes (G being the common centre of gravity, R the centre of gravity of the matter contained in this line, and O the centre of oſcillation). Let this weight deſcend from reſt through any convenient ſpace s inches, and let the obſerved time of its deſcent be t ſeconds; then if l be the ſpace through which bodies deſcend freely by gravity in one ſecond, the equivalent weight ſought $= \frac{W\times SR\times SO}{SD^2} = \frac{P\times t^2 l}{s} - P$. See art. 314. vol. i.

Here we have $p = 30$ grains, $t = 3$ ſeconds, $l = 193$ inches, $s = 38.5$ inches; and $\frac{P \times t^2 l}{s} - P = \frac{30 \times 9 \times 193}{385} - 30 = 1323$ grains or $2\frac{3}{4}$ ounces.

This is the inertia equivalent to that of the wheel *abcd*, and the friction wheels together: for the rule extends to the eſtimation of the inertia of the maſs contained in all the wheels.

The reſiſtance to motion therefore ariſing from the wheels' inertia, will be the ſame as if they were abſolutely removed, and a maſs of $2\frac{3}{4}$ ounces were uniformly accumulated in the circumference of the wheel *abcd*. This being premiſed, let the boxes A and B, fig. 1. be replaced, being ſuſpended by the ſilk line over the wheel or pulley *abcd*, and balancing each other: ſuppoſe that any weight *m* be added to A ſo that it ſhall deſcend, the exact quantity of matter moved, during the deſcent of the weight A, will be aſcertained, for the whole maſs will be $A + B + m + 2\frac{3}{4}$ oz.

In order to avoid troubleſome computations in adjuſting the quantities of matter moved and the moving forces, ſome determinate weight of convenient magnitude may be aſſumed as a ſtandard, to which all the others are referred. This ſtandard weight in the ſubſequent experiments is $\frac{1}{4}$ of an ounce, and is repreſented by the letter *m*. The inertia of the wheels being therefore $= 2\frac{3}{4}$ ounces, will be denoted by 11 *m*. A and B are two boxes conſtructed ſo as to contain different quantities of matter, according as the experiment may require them to be varied: the weight of each box, including the hook to which it is ſuſpended, $= 1\frac{1}{2}$ oz. or according to the preceding eſtimation, the weight of each box will be denoted by 6 *m*; theſe boxes contain ſuch weights as are repreſented by fig. 3. each of which weighs an ounce, ſo as to be equivalent to 4 *m*; other weights of $\frac{1}{2}$ oz. $= 2m$, $\frac{1}{4} = m$, and aliquot parts of *m*, ſuch as $\frac{1}{2}$, $\frac{1}{4}m$, may be alſo included in the boxes, according to the conditions of the different experiments hereafter deſcribed.

If $4\frac{3}{4}$ oz. or 19 *m*, be included in either box, this, with the weight of the box itſelf, will be 25 *m*; ſo that when the weights A and B, each being 25 *m*, are balanced in the manner above repreſented, their whole maſs will be 50 *m*, which being added to the inertia of the wheels 11 *m*, the ſum will be 61 *m*. Moreover, three circular weights, ſuch as that which is repreſented at fig. 4. are conſtructed; each of which $= \frac{1}{4}$ oz. or *m*: if one of theſe be added to A and one to B, the whole maſs will now become 63 *m*, perfectly in equilibrio, and moveable by the leaſt weight added to either (ſetting aſide the effects of friction), in the ſame manner preciſely as if the ſame weight or force were applied to communicate motion to the maſs 63 m, exiſting in free ſpace and without gravity.

2. *The moving force.* Since the natural weight or gravity of any given ſubſtance is conſtant, and the exact quantity of it eaſily eſtimated, it will be convenient here to apply a weight to the maſs A as a moving force: thus, when the ſyſtem conſiſts of a maſs $= 63\ m$, according to the preceding deſcription, the whole being perfectly balanced, let a weight $\frac{1}{4}$ oz. or m, ſuch as is repreſented in fig. 5. be applied on the maſs A; this will communicate motion to the whole ſyſtem: by adding a quantity of matter m to the former maſs 63 m, the whole quantity of matter moved will now become 64 m; and the moving force being $= m$, this will give the force which accelerates the deſcent of A $= \frac{m}{64m}$, or $\frac{1}{64}$ part of the accelerating force by which the bodies deſcend freely towards the earth's ſurface.

By the preceding conſtruction, the moving force may be altered without altering the maſs moved: for ſuppoſe the three weights m, two of which are placed on A, and one on B to be removed, then will A balance B. If the weights 3 m be all placed on A, the moving force will now become 3 m, and the maſs moved 64 m as before, and the force which accelerates the deſcent of A $= \frac{3m}{64m} = \frac{3}{64}$ parts of the force by which gravity accelerates bodies in their free deſcent to the ſurface.

Suppoſe it were required to make the moving force 2 m, the maſs moved continuing the ſame. In order to effect this, let the three weights, each of which $= m$, be removed; A and B will balance each other; and the whole maſs will be 61 m: let $\frac{1}{2}\ m$, fig. 5. be added to A, and $\frac{1}{2}m$ to B, the equilibrium will ſtill be preſerved, and the maſs moved will be 62 m; now let 2 m be added to A, the moving force will be 2 m, and the maſs moved 64 m, as before; wherefore the force of acceleration $= \frac{1}{32}$ part of the acceleration of gravity. Theſe alterations in the moving force may be made with great eaſe and convenience in the more obvious and elementary experiments, there being no neceſſity for altering the contents of the boxes A and B: but the proportion and abſolute quantities of the moving force and maſs moved may be of any aſſigned magnitude, according to the conditions of the propoſition to be illuſtrated.

3. *Of the ſpace deſcribed.* The body A fig. 1. deſcends in a vertical line; and a ſcale about 64 inches in length graduated into inches and tenths of an inch is adjuſted vertically, and ſo placed that the deſcending weight A may fall in the middle of a ſquare ſtage, fixed to receive it at the end of the deſcent: the beginning of the deſcent is eſtimated from 0 on the ſcale, when

the bottom of the box A is on a level with o. The deſcent of A is terminated when the bottom of the box ſtrikes the ſtage, which may be fixed at different diſtances from the point o; ſo that by altering the poſition of the ſtage, the ſpace deſcribed from quieſcence may be of any given magnitude leſs than 64 inches.

4. *The time of motion* is obſerved by the beats of a pendulum, which vibrates ſeconds; and the experiments, intended to illuſtrate the elementary propoſitions, may be eaſily ſo conſtructed that the time of motion ſhall be a whole number of ſeconds: the eſtimation of the time, therefore, admits of conſiderable exactneſs, provided the obſerver takes care to let the bottom of the box A begin its deſcent preciſely at any beat of the pendulum; then the coincidence of the ſtroke of the box againſt the ſtage, and the beat of the pendulum at the end of the time of motion, will ſhew how nearly the experiment and the theory agree together. There might be various mechanical devices thought of for letting the weight A begin its deſcent at the inſtant of a beat of the pendulum W: let the bottom of the box A, when at o on the ſcale, reſt on a flat rod, held in the hand horizontally, its extremity being coincident with o, by attending to the beats of the pendulum; and with a little practice the rod which ſupports the box A may be removed at the moment the pendulum beats, ſo that the deſcent of A ſhall commence at the ſame inſtant.

5. *Of the velocity acquired.* It remains only to deſcribe in what manner the velocity acquired by the deſcending weight A, at any given point of the ſpace through which it has deſcended, is made evident to the ſenſes. The velocity of A's deſcent being continually accelerated, will be the ſame in no two points of the ſpace deſcribed. This is occaſioned by the conſtant action of the moving force; and ſince the velocity of A at any inſtant is meaſured by the ſpace which would be deſcribed by it, moving uniformly for a given time with the velocity it had acquired at that inſtant, this meaſure cannot be experimentally obtained, except by removing the force by which the deſcending body's acceleration was cauſed.

In order to ſhew in what manner this is affected practically, let us again ſuppoſe the boxes A and B = 25 *m* each, ſo as together to be = 50 *m*; this, with the wheel's inertia 11 *m*, will make 61 *m*; now let *m*, fig. 3. be added to A, and an equal weight *m* to B, theſe bodies will balance each other, and the whole maſs will be 63 *m*. If a weight *m* be added to A, motion will be communicated, the moving force being *m*, and the maſs moved 64 *m*. In eſtimating the moving force, the circular weight = *m* was made uſe of as a moving force: but for the preſent purpoſe of ſhewing the velocity acquired, it will be convenient to uſe a flat rod, the weight of which is alſo $= m$. Let the bottom of the box A be placed on a level with o on the ſcale, the whole maſs being as deſcribed above $= 63\,m$, perfectly balanced in equilibrio. Now let the rod, the weight of which $= m$, be placed on the upper ſurface of A; this body will deſcend along the ſcale preciſely in the ſame manner as when the moving force was applied in the form of a circular weight. Suppoſe the maſs A, fig. 6, to have deſcended by conſtant acceleration of force of m, for any given time, or through a given ſpace: let a circular frame be ſo affixed to the ſcale, contiguous to which the weight deſcends, that A may paſs centrally through it, and that this circular frame may intercept the rod m, by which the body A has been accelerated from quieſcence. After the moving force m has been intercepted at the end of the given ſpace or time, there will be no force operating on any part of the ſyſtem which can accelerate or retard its motion: this being the caſe, the weight A, the inſtant after m has been removed, muſt proceed uniformly with the velocity which it hadacquired that inſtant: in the ſubſequent part of its deſcent, the velocity, being uniform, will be meaſured by the ſpace deſcribed in any convenient number of ſeconds.

Other uſes of the inſtrument it is needleſs to deſcribe particularly, but it may not be improper to mention ſome of them; ſuch as the experimental eſtimation of the velocities communicated by the impact of bodies elaſtic and non-elaſtic; the quantity of reſiſtance oppoſed by fluids, as well as for various other purpoſes. Theſe uſes we ſhall not inſiſt on; but the properties of retarded motion being a part of the preſent ſubject, it may be neceſſary to ſhew in what manner the motion of bodies reſiſted by conſtant forces are reduced to experiment by means of the inſtrument above deſcribed, with as great eaſe and preciſion as the properties of bodies uniformly accelerated. A ſingle inſtance will be ſufficient: Thus, ſuppoſe the maſs contained in the weights A and B, fig. 6, and the wheels to be $61\,m$, when perfectly in equilibrio; let a circular weight m be applied to B, and let two long weights or rods, each $= m$, be applied to A, then will A deſcend by the action of the moving force m, the maſs moved being $64\,m$: ſuppoſe that when it has deſcribed any given ſpace by conſtant acceleration, the two rods m are intercepted by the circular frame above deſcribed, while A is deſcending through it, the velocity acquired by that deſcent is known; and when the two rods are intercepted, the weight A will begin to move on with the velocity acquired, being now retarded by the conſtant force m; and ſince the maſs moved is $62\,m$, it follows, that the force of retardation will be $\frac{1}{62}$ part of that force whereby gravity retards bodies thrown perpendicularly upwards. The weight A will therefore proceed along the graduated ſcale in its deſcent with an uniformly retarded motion, and the ſpace deſcribed, times of motion, and velocities deſtroyed by the reſiſting force, will be ſubject to the ſame meaſures as in the examples of accelerated motion above deſcribed.

In the foregoing deſcriptions, two ſuppoſitions have been aſſumed, neither of which is mathematically true: but it may be eaſily ſhewn that they are ſo in a phyſical ſenſe; the errors occaſioned by them in practice being inſenſible.

1. The force which communicates motion to the ſyſtem has been aſſumed conſtant; which will be true only on a ſuppoſition that the line, at the extremities of which the weights A and B, fig. 1. are affixed, is without weight. In order to make it evident that the line's weight and inertia are of no ſenſible effect, let a caſe be referred to, wherein the body A deſcends through 48 inches from reſt by the action of the moving force *m*, when the maſs moved is 64 *m*; the time wherein A deſcribes 48 inches is increaſed by the effects of the line's weight by no more than $\frac{312}{10000}$th parts of a ſecond: the time of deſcent being 3.9896 ſeconds, when the ſtring's weight is not conſidered, and the time when the ſtring's weight is taken into account=4.0208 ſeconds; the difference between which is wholly inſenſible by obſervation.

2. The bodies have alſo been ſuppoſed to move in vacuo, whereas the air's reſiſtance will have ſome effect in retarding their motion: but as the greateſt velocity communicated in theſe experiments cannot much exceed that of about 26 inches in a ſecond (ſuppoſe the limit 26.2845), and the cylindrical boxes being about $1\frac{1}{4}$ inches in diameter, the air's reſiſtance can never increaſe the time of deſcent in ſo great proportion as that of 240 : 241; its effects therefore will be inſenſible in experiment.

The effects of friction are almoſt wholly removed by the friction wheels; for when the ſurfaces are well poliſhed and free from duſt, &c. if the weights A and B be balanced in perfect equilibrio, and the whole maſs conſiſts of 63 *m*, according to the example already deſcribed, a weight of $1\frac{1}{2}$ grain, or at moſt 2 grains, being added either to A or B, will communicate motion to the whole; which ſhews that the effects of friction will not be ſo great as a weight of $1\frac{1}{2}$ or 2 grains. In ſome caſes, however, eſpecially in experiments relating to retarded motion, the effects of friction become ſenſible; but may be very readily and exactly removed by adding a ſmall weight of 1.5 or 2 grains to the deſcending body, taking care that the weight added is ſuch as is in the leaſt degree ſmaller than that which is juſt ſufficient to ſet the whole in motion, when A and B are equal, and balance each other before the moving force is applied. *Atwood on Motion*, p. 316.

BALANCE, as diſtinguiſhed from the Steelyard, is a lever with equal arms, whoſe fulcrum or centre of motion is ſituated immediately above the centre of gravity of the beam, when horizontal: it is uſed chiefly in determining the equality or difference in the weights of different bodies.

Some remarks on the nature of the balance were made when we treated of the lever in the firſt volume; where alſo we ſhewed how to correct the deception occaſioned by a falſe balance: in addition to what was there ſtated, we ſhall now preſent a few ſuch obſervations as may be moſt ſerviceable in directing the accurate conſtruction of this inſtrument.

1. The axis of motion of the balance ſhould be above the centre of gravity of the beam.

2. A ſlender index, or *tongue* (as it is called), paſſes through the centres of gravity and motion of the beam, perpendicular to its axis: by this index the horizontal poſition of the beam, when loaded, in the compariſon of weights, is determined.

3. When the balance unloaded is quieſcent, and therefore horizontal, if the index which paſſes through the fulcrum be directed to any fixed point; and again when the balance is reverſed, it be directed to the ſame fixed point; it is in the right line which joins the centre of gravity and the fulcrum.

By this means the poſition of the index is adjuſted.

4. The perpendicular diſtances of the points of application of the weights to be compared, from the right line which joins the centres of gravity and of motion, ſhould be equal, that is, the arms of the balance ought to be equal.

5. The points of application from which the weights are ſuſpended, ſhould be in the ſame right line perpendicular to the line joining the centres of gravity and of motion.

6. The nearer the right line joining the points of application is to the centre of motion, the larger vibrations of the balance, and a more ſenſible effect, will be produced.

7. If the centre of motion be ſituated below the line joining the points of application, the beam, when loaded with equal weights, will overſet, reſt in any poſition, or equilibrate, according to the weight.

8. When two given weights, ſuſpended from the arms of a balance, are in equilibrio, if theſe weights when transferred to the oppoſite ſcales be ſtill in equilibrio, the arms of the balance are equal.

9. The various adjuſtments of the balance are theſe: 1ſt. equal weights are readily found, whatever be the ſtate of the

balance; for, if they reduce the beam to the ſame poſition, when ſucceſſively applied to the ſame arm, they muſt be equal: then if theſe equal weights tranſpoſed do not diſturb the poſition of the beam, the arms are equal. 2dly. If unequal weights tranſpoſed produce equal deflections of the beam, the points of ſuſpenſion are in the ſame right lines, perpendicular to that which joins the centre of gravity and motion; and therefore the line joining theſe points will be horizontal when the beam hangs freely. 3dly. Let the index be directed to any fixed point, then the beam being reverſed, if it ſtill paſs through the ſame point, the index is perpendicular to the axis of the beam.

10. The equilibrium of the balance will be affected by the tongue, unleſs it be continued below the centre of motion, ſo that the momenta on both ſides may be equal and oppoſite.

11. Minute differences of weight are rendered more diſcernible by diminiſhing the friction upon the axis, as by ſuſpending it in a fork with ſprings, &c.

Indeed when balances are required for accurate philoſophical purpoſes, much caution is requiſite in the various parts of the conſtruction, and many peculiar contrivances have been adopted: ſome of the beſt of theſe are given in the following article.

Hydroſtatic BALANCE, is an inſtrument contrived to determine accurately the ſpecific gravity of both ſolid and fluid bodies. One of the moſt ingenious forms of this balance is exhibited in fig. 5. pl. VI. where VCG is the ſtand or pillar, which is to be fixed in a table. From the top A hangs by two ſilk ſtrings the horizontal bar BB, from which is ſuſpended by a ring *i* the fine beam of a balance *b*; which is prevented from deſcending too low on either ſide by the gently ſpringing piece *t x y z*, fixed on the ſupport M. The harneſs is annulated at *o*, to ſhew diſtinctly the perpendicular poſition of the examen, by the ſmall pointed index fixed above it.

The ſtrings by which the balance is ſuſpended, paſſing over two pulleys, one on each ſide the piece at A, go down to the bottom on the other ſide, and are hung over the hook at *v*; which hook, by means of a ſcrew P, is moveable to about the diſtance of an inch and a quarter backward and forward, and therefore the balance may be raiſed or depreſſed ſo much. But if a greater elevation or depreſſion be required, the ſliding piece which carries the ſcrew P, is readily removed to any part of the ſquare braſs rod VK, and fixed by means of a ſcrew.

The motion of the balance being thus adjuſted, the reſt of the apparatus is as follows: HH is a ſmall board fixed upon the piece D, under the ſcales *d* and *e*, and is moveable up and down in a low ſlit in the pillar above C, and faſtened at any part by a ſcrew behind. From the point in the middle of the bottom of each ſcale hangs, by a fine hook, a braſs wire *a d*, and *a c*: theſe paſs through two holes *m*, *m*, in the table. To the wire *a d* is ſuſpended a curious cylindric wire *r s*, perforated at each end for that purpoſe: this wire *r s* is covered with paper graduated by equal diviſions, and is about five inches long.

In the corner of the board at E is fixed a braſs tube, on which a round wire *h l* is ſo adapted as to move neither too tight nor too freely, by its flat head I. Upon the lower part of this moves another tube Q, which has ſufficient friction to make it remain in any poſition required: to this is fixed an index T, moving horizontally when the wire *h l* is turned about, and may therefore be eaſily ſet to the graduated wire *r s*. From the lower end of the wire *r s* hangs a weight L; and from that a wire *p n*, with a ſmall braſs ball *g* about one fourth of an inch diameter. On the other ſide from the wire *a c* hangs a large glaſs bubble R, by a horſe-hair.

Now, let us ſuppoſe the weight L taken away, and the wire *p n* ſuſpended from *s*: and on the other ſide let the bubble R be taken away, and a weight, as F, ſuſpended at *c* in its room. This weight F we ſuppoſe to be ſufficient to keep the ſeveral parts hanging from the other ſcale in equilibrium; at the ſame time that the middle point of the wire *p n* is at the ſurface of the water in the veſſel O. The wire *p n* is to be of ſuch a ſize that the length of one inch ſhall weigh four grains.

Now it is evident, ſince braſs is about eight times heavier than water, that for every inch the wire ſinks in the water, it will become half a grain lighter; and half a grain heavier for every inch it riſes out of the water: conſequently, by ſinking two inches below the middle point, or riſing two inches above it, the wire will become in effect one grain lighter or heavier. If, therefore, when the middle point is at the ſurface of the water in equilibrio, the index T be ſet to the middle point of the graduated wire *r s*, and the diſtance of *r* and of *s* from the index be each reckoned to contain 100 equal parts; then, if in weighing bodies the weight is required to the hundredth part of a grain, it may be eaſily obtained by proceeding thus:—Let the body to be weighed be placed in the ſcale *e*; and let this be ſo determined that one grain more ſhall be too much, and one grain leſs too little. Then the balance being moved gently up or down by the ſcrew P till the equilibrium be nicely ſhewn at *o*, if the index T be at the middle point of the wire *r s*, it ſhews that the weights put into the ſcale *e* are juſt equal to the weight of the body.

But if the index T ſtand nearer to *r* than to *s*, as ſuppoſe 36 of the 100 parts, it ſhews the number of grains in the ſcale *e* were leſs than equal to the weight of the body in ſcale *d*, by 36 hundredths of a grain: and if, on the other hand, the index had ſtood at the diviſion 36 below the middle point of *r s*, then would the grains in the ſcale *e* indicate more than the real weight in *d* by 36 hundredths of a grain.

Inſtead of putting the body in the ſcale *d* as before, let it be appended with the weight F at the hook *c* by a horſe-hair, as at R, ſuppoſing the veſſel of water were away; then obſerve the equilibrium, and as it hangs, let it be immerſed in the water of the veſſel O, and it will become much lighter; the number of grains and parts of grains, determined as before, required to reſtore the equilibrium, will ſhew the weight of water equal in bulk to the body immerſed.

In practice, the wire *p n* ſhould be oiled, and then wiped as clean as poſſible; enough will remain to prevent the water adhering to it. The balance ought to be raiſed very gently, and when brought to an equilibrium ſhould be gently agitated, to ſee whether it will return to the equilibrium again.

For the deſcription of M. Paul's accurate ſteelyard to anſwer the ſame purpoſes, ſee the article STEELYARD.

M. Prony, of whom we have often had occaſion to ſpeak, has invented a ſtand or ſupport for balances of all dimenſions, which is calculated to render the operations for which theſe inſtruments are uſed, more expeditious and convenient, without diminiſhing their accuracy. His account is publiſhed in the Annales de Chimie, xxxvi. 50.

"Several experiments," ſays he, "in which I was engaged during the courſe of the laſt winter, put me under the neceſſity of contriving a ſupport which might be applied promiſcuouſly to every kind of balance, whether provided with a ſuſpending handle or not, and which, without detriment to its accuracy, ſhould afford me commodious means of ſucceſſively raiſing and lowering it. It is well known how embarraſſing and laborious the operation of weighing is, when performed with balances ſupported by the hand; though this is often only the ſmalleſt inconvenience with which their uſe is attended.

"Various artiſts have contrived ſupports, commodious in their uſe, and ingenious in their principle; but as each of theſe ſupports can only be adapted to a ſingle balance, they become ſo expenſive as to be out of the reach of the majority of artiſts and experimentaliſts. I think, therefore, I ſhall do them an acceptable ſervice by publiſhing, in compliance with the requeſt of ſeveral eminent chemiſts, the deſcription of a ſupport, which, beſides the advantage of being adapted for all kinds of balances, poſſeſſes that of being conſtructed, at a ſmall expenſe, either in wood or metal.

"A triangular foot of braſs A *a*, *a*, *a* (figs. 1. and 2. plate

VI. repreſenting the elevation and ſection of my apparatus), has its three extremities *a*, *a*, *a*, firmly ſcrewed down upon a table or horizontal plane. Into the part A of this foot is ſcrewed a cylindrical rod A B, which may be of any arbitrary length: it may even be convenient to have two of theſe of different lengths, in order that they may be changed, when we wiſh to employ the machine for very large balances. Thoſe which I have made uſe of are, the one half a metre, and the other one metre (39·4 inches) in length.

“ A vertical pulley, P, is placed at the top of the ſtem A B, in ſuch a manner that the ſame vertical plane paſſes through the axis of the rod, and through the horizontal axis of the pulley; the block or collar CD of this pulley has at its lower part a tube CB, into which enters, with a gentle friction, the ſuperior extremity of the rod AB; a ſcrew, E, ſerves to keep the pulley in a fixed poſition.

“ Another pulley, P, is fixed at the bottom of the rod AB, in ſuch a poſition that the tangent of the pulleys P and P is parallel to the axis of the rod AB.

“ A cord K *t p* HGPF, to the end of which is ſuſpended on the outſide of the vertical table K a ſmall weight *k*, paſſes through a hole *t* made in the foot *a*, rolls over the pulleys *p* and P, and is attached at F to a piece *m m' n q*, which has the form of a fork, and to which are ſuſpended (as I ſhall ſhortly explain) the balance, the weights, and the ſubſtances that are to be weighed. F *m* is a button, which being ſcrewed at the top of the fork, receives the end of the cord, and by means of a knot made on it ſuſtains the fork.

“ The tail or handle of this fork is of a priſmatic form at the part *m' n*; this priſmatic part enters a groove *f f* made at the extremity N of the horizontal piece NO, ſo that it can ſlide freely in this groove either upwards or downwards, its courſe being however limited at *m'*, where it is ſtopped by the enlarged handle of the fork, and at *n* by the greater width produced by the ſeparation of the two branches of the fork.

“ The piece NO, which is hollow, and interſected at O by the ſtem AB, can ſlide along and turn round this ſtem: when it is brought to its proper height, it is ſecured by means of the ſcrew V, and it is then neceſſary, firſt, that it ſhould be at ſuch a height that, when the ſtop *m* reſts on the ſide of the groove *f f*, or when NO can move no further down, the ſcale of the balance ſhall be in contact with the table or horizontal plane, in order that we may afterwards be able to raiſe it the whole height of *f n*; ſecondly, that the cord FF be in one and the ſame vertical plane with HG.

"The groove at N ought to be ſituated in ſuch a manner that the axis of the priſmatic part of the tail of the fork, and the cord FF^1, ſhall always be in the ſame verticle plane, or in a parallel line with the axis of the ſtem AB.

"Theſe diſpoſitions being made, let us imagine the two branches *n q* of the fork to be perforated with holes of different diameters, in order to receive horizontal pins *(g g)* of different ſizes; and we ſhall have all that is requiſite for the ordinary operations of weighing, performed in the air with balances, the beams of which are ſuſpended from above.

"In fact, whatever kind of balance we uſe, we are to introduce the extremity of its ſuſpending handle into the fork *n q*, and inſert into the round hole, which the handle of the balance always has at its ſuperior extremity, any one of the pins that will enter with eaſe; we then apply the piece ON in ſuch a manner as to fulfil the conditions above laid down for the poſition of this piece; after which, it is to be fixed by the ſcrew V. This being done, the ſcales of the balance are to be charged, which being in contact with the table, or horizontal plane, can have no motion. When the ſcales are charged, we lay hold of the ſmall ball *k*, and draw the cord which ſuſpends it ſo as to raiſe the balance very ſlowly: if the ſcales be not in equilibrio, the cord is to be looſened till they reſt again upon the table, and ſo ſucceſſively.

"A counterpoiſe, Q, ſuſpended to the cord FG, ought to preſerve the equilibrium with the weight of the balance. By means of this precaution, it comes to paſs, that the common centre of gravity of all the forces ſupported by the pulley P, falls in all caſes upon the axis of the ſtem AB, which thus has no tendency to bend.

"If we wiſh now to uſe a hydroſtatic balance, we adapt to the ſtem AB a ſmall board ON, fig. 3. which, by means of a cylindrical hole at O, may ſlide along the rod AB, and be fixed at any arbitrary height by a ſcrew at V. Another piece, or board, $K^1 K^1$, is placed upon $V^1 N^1$, in ſuch a manner that the holes TT correſpond with the centre of the ſcales, under which are placed the hooks intended for holding the ſubſtances ſuſpended in the water, and $K^1 K^1$ is fixed upon $V^1 N^1$ by means of ſcrews V^1.

"Theſe arrangements being made, let the piece $N^1 O^1$ and the board $K^1 K^1$, be placed in ſuch a manner that, firſt, the whole height of the balance be placed between this piece and the board, and that the ſcales L L be in contact with the board $K^1 K^1$, their centres correſponding with holes made in TT. Secondly, that $K^1 K^1$ be ſufficiently elevated to enable us to place under it the veſſels WW, filled with water, and conveniently to immerſe, in one of theſe veſſels, the ſubſtances which we wiſh to weigh hydroſtatically.

"According to the common practice, theſe ſubſtances are ſuſpended by a very thin wire; but by placing after my method, two veſſels, and ſuſpending to the two ſcales wires of equal diameter, the one of which ſupports the ſubſtance that is to be weighed, and the other merely in part immerſed, the magnitude of the diameter will have no influence upon the accuracy of the operation; for, let us ſuppoſe the apparatus to be adjuſted in ſuch a manner that at firſt the two wires were in equilibrio with each other (which may eaſily be obtained by varying the height of the water in the veſſels), theſe two wires will ſtill be in equilibrio, when the beam FF^1, being elevated, will remain in its horizontal poſition: whence it follows, that if one of the wires have ſuſpended from it a ſubſtance immerſed in the water, and we place in the oppoſite ſcale, and conſequently out of the water, a weight adequate to keep the equilibrium with the immerſed ſubſtance, for a horizontal poſition of the beam, the equilibrium will ſtill be maintained, whatever may be the elevation or depreſſion of the beam, provided it continue in a horizontal poſition; for the lengths of the wires, either above or below the ſurface of the water, being equal, the difference between the ſpecific weight of the water and that of the metal will operate equally upon both extremities of the beam. It is evident that this advantage will not be obtained if we employ only the wire to which the ſubſtance is ſuſpended, and that the equilibrium, eſtabliſhed for a certain elevation and a horizontal poſition of the beam, will not apply to other elevations of the beam by preſerving it in the horizontal poſition.

"It is to be remarked, that my method compenſates not only for the exceſs of the ſpecific weight of the wires over that of the water, but alſo for that which depends upon the adheſion of the fluid to the wires, and the covering of water which they carry along with them.

"All that has been ſaid hitherto applies only to balances that are provided with ſuſpending handles; but, in order to render this ſupport abſolutely univerſal in its uſe, it was neceſſary that it ſhould be poſſible to adapt it to a beam which had nothing but its centres; for which purpoſe I contrived an apparatus, which is ſuſpended, like thoſe of a common balance, to the fork *n q*, and which may receive the centres of any beam. The engraved plates of my machine repreſent it provided with this apparatus, the conſtruction of which is as follows.

"A piece *s s*^{1} has a ſcrewed hole bored into it at *s*^{1}, into which the ſcrew $d d$ is inſerted half its length. Another hole, made at s, in a perpendicular direction to the firſt, receives the pin $g g$, to which all the inferior apparatus is ſuſpended. This hole s ſupplies the place of that which is found at the upper extremity of the ſuſpending handle of balances.

“ The two other vertical pieces r, r, fig. 4, have at their upper part cylindrical holes not ſcrewed, in which the ſcrew $d d$ can turn freely. Theſe ſuperior parts are placed at an arbitrary diſtance, and retained in their ſituation by means of four nut-ſcrews u, u, u, u, each of the pieces being faſtened between two of theſe nut-ſcrews. A cylindrical rod $h h$ traverſes the inferior parts of theſe pieces $r r$, and is fixed there by means of nut-ſcrews, in ſuch a manner that the ſuperior and inferior points of the pieces $r r$ are invariably at the ſame diſtance.

“ Each of theſe pieces $r r$ has, upon the ſurface which is perpendicular to the direction of $d d$ and $h h$, a groove $e e$, and a circular aperture X, having at its lower part a ſmall bracket of poliſhed ſteel $a a$, intended to ſupport one of the centres of the beam. Into the upper part of the grooves $e e$ a rule $e' e'$ is introduced, which muſt enter with tightneſs, and which, with the pieces $d d$ and $h h$, give ſuch a ſolidity to the apparatus, that the adjuſtment of its parts cannot be in the ſmalleſt degree deranged. The remainder of the groove, which is not occupied by $e' e'$, ought to be of a length ſomewhat greater than that of the largeſt cock or index adapted to the beams which we ſhall have to uſe.

“ The method of uſing the apparatus which I have juſt deſcribed is very ſimple. The beam which we intend to employ is placed between the two branches $r r$, which are removed from each other till the centres can be brought oppoſite to the circular holes X; the pieces r, r, are then brought together in ſuch a manner that the centres enter theſe holes X, and ſo as ſtill to leave ſome room for motion between theſe pieces and the body of the beam, in order that the oſcillations of the balance may be perfectly free. The pieces r, r, are brought parallel with each other, and the adjuſtment of the apparatus is rendered perfectly firm, by means of nut-ſcrews, by the ſmall cylindrical rod $h h$, and by the rule $e' e'$. The apparatus being adjuſted in this manner, it is ſuſpended to the fork $n q$, by inſerting the pin $g g$ into the hole s, and the balance is uſed in the manner that has already been explained. We know the equilibrium to be eſtabliſhed, and the beam to be horizontal, when the index $y y$ divides the breadth of the ſpace $e e$ into two equal parts; but, in order to aſcertain the circumſtance with greater accuracy, I have attached to the rule $e' e'$ a plummet $e' i'$, by means of which we may diſtinguiſh the ſlighteſt deviations of the index from the perpendicular direction."

Daniſh BALANCE, is a kind of balance or ſteelyard in common uſe in many parts of the continent of Europe, and is of a very ſimple conſtruction. It is thus deſcribed in the *Encyclopædia Britannica* (art. *Steelyard*): "It conſiſts of a batten of hard wood, having a heavy lump K (fig. 7. pl. VI.) at one end, and a ſwivel hook *b* at the other. The goods to be weighed are ſuſpended on the hook, and the whole is carried in a loop of whipcord F, in which it is ſlid backward and forward till the goods are balanced by the weight of the other end. The weight of the goods is eſtimated by the loop on a ſcale of diviſions in harmonic progreſſion. They are marked (we preſume) by trial with known weights."

It would ſeem, then, that the writer of the article, whence the above is extracted, was not aware that the diviſions on the Daniſh balance might be effected by a method purely geometrical: yet M. *Roemer* pointed out ſuch a method more than a century ago, in *Recueil des Machines appr. par L'Acad. Roy. Sci.* tom. 1. pa. 80. It is in ſubſtance as follows. Let AC (figs. 7. 8.) be the diſtance between the point A from which the body whoſe weight is to be determined is ſuſpended, and C the centre of gravity of the balance when the weight W is not attached to it. From the point C draw an indefinite line CD, making any angle ACD with the line AC on which the diviſions of the balance are to be marked; and through A draw another right line AN parallel to CD. Set off any equal diſtances CE, EF, FG, GH, HI, &c. along the line CD; and upon AN ſet off the diſtance AB equal to one of the equal diſtances, as CE, upon CD. From B as a fixed point draw lines BE, BF, BG, BH, &c. to the ſeveral points of diviſion on CD; and they will interſect the line AC, in the points 1, 2, 3, 4, 5, &c. where the ſubdiviſion marks ought to ſtand in the balance, fig. 7. The numbers 1, 2, 3, 4, &c. fig. 8. denote ſo many times the actual weight of the balance and its knobs, independent of the adventitious weight W. Thus if the unloaded balance weigh 6lbs, the diſtances marked 1, 2, 3, 4, 5, &c. in fig. 8. would correſpond to the ſubdiviſion marks, 6, 12, 18, 24, 30, &c. in fig. 7.

M. Roemer has not demonſtrated the truth of this conſtruction: but it may be eaſily ſhewn thus: Let *w* be the weight of the balance and knob, and W that of the body which is to be aſcertained by the inſtrument. Then, when the point of ſuſpenſion is that marked 1, fig. 8. we have in the triangles AB 1, 1 CE, the ſides AB and CE equal, alſo angle $BA1 = 1CE$, and $B1A = E1C$; therefore theſe triangles are both equiangular and equilateral; conſequently, $A1 = 1C$, and by the natures of the lever, and the centre of gravity $W=w$. Again, in like manner when the point of ſuſpenſion is 2, the triangles AB 2, 2 CF, are equiangular; and ſince $FC=2\ AB$, we have $C\ 2=2\ A\ 2$, and $W=2w$. So alſo the triangles AB 3, 3 CG, are equiangular; whence becauſe $CG=3\ AB$, $C\ 3=3\ A\ 3$, and $W=3w$. And ſo on, through the whole diviſion.

This balance has been deſcribed more on account of its curioſity than actual utility: for in aſcertaining large weights it would be extremely cumberſome and difficult to manage. In the determination of weights not exceeding twenty or thirty pounds, it might, however, be rendered very manageable: for it might be about the length of an exciſeman's rod, or a walking ſtick, having a knob of lead at one end; and in this caſe the diviſions near the knob might be ſo numerous as to enable a perſon to weigh accurately to quarters of pounds, if not to ounces: the rod might be moved to and fro upon a chair-back, or the edge of a treſſel; and thus this inſtrument might often be more conveniently uſed than a ſpring ſteelyard.

Balance *of a Clock or Watch*, is that part which, by its motion, regulates and determines the beats. The circular part of it is called the *rim*, and its ſpindle the *verge*; there belong to it alſo two pallets or nuts, that play in the fangs of the crown-wheel: in pocket watches that ſtrong ſtud in which the lower pivot of the verge plays, and in the middle of which one pivot of the crown-wheel runs, is called the *potence*: the wrought piece which covers the balance, and in which the upper pivot of the balance plays, is the *cock*; and the ſmall ſpring in the new pocket watches is called the *regulator*.

The motion of a balance, as well as that of a pendulum, being reciprocating, while the preſſure of the wheels is conſtantly in one direction, it is obvious that ſome art muſt be uſed to accommodate the one to the other. When a tooth of the wheel has given the balance a motion in one direction, it muſt quit it, that it may get an impulſion in the oppoſite direction. The balance or pendulum thus eſcaping from the tooth of the wheel, or the tooth eſcaping from the balance, has given to the general conſtruction the name of ſcapement among our artiſts. See Scapement.

Some of the moſt important propoſitions relative to watch balances may be conciſely ſtated as follows: 1. The balance of a watch is analogous to the pendulum in its properties and uſe. The ſimple balance is a circular annulus, equally heavy in all its parts, and concentrical with the pivots of the axis on which it is mounted. This balance is moved by a ſpiral ſpring called the balance ſpring, the invention of Mr. Hook.

2. The pendulum requires a leſs maintaining power than

the balance. Hence the natural iſochroniſm of the pendulum is leſs diſturbed by the relatively ſmall inequalities of the maintaining power.

3. The elaſtic force of the ſpring which impels the circumference of the balance is directly as the tenſion of the ſpring; that is, the weights neceſſary to counterpoiſe a ſpiral ſpring's elaſtic force, when the balance is wound to different diſtances from the quieſcent point, are in the direct ratio of the arcs through which it is wound.

4. The vibrations of a balance, whether through great or ſmall arcs, are performed in the ſame time. For the accelerating force is directly as the diſtance from the point of quieſcence: hence, therefore, the motion of the balance is analogous to that of a pendulum vibrating in cycloidal arches (vol. i, art. 276.)

5. The time of the vibration of a balance is the ſame as if a quantity of matter, whoſe inertia is equal to that by which the maſs contained in the balance oppoſes the communication of motion to the circumference, deſcribed a cycloid whoſe length is equal to the arc of vibration, deſcribed by the circumference, the accelerating force being equal to that of the balance.

6. The times of vibration of different balances are in a ratio compounded of the direct ſubduplicate ratios of their weights and ſemidiameters, and the inverſe ſubduplicate ratio of the tenſions of the ſprings, or of the weights which counterpoiſe them, when wound through a given angle.

7. The times of vibration of different balances are in a ratio compounded of the direct ſimple ratio of the radii and direct ſubduplicate ratio of their weights, and the inverſe ſubduplicate ratio of the abſolute forces of the ſprings at a given tenſion.

8. Hence the abſolute force of the balance ſpring, the diameter and weight of the balance being the ſame, is inverſely as the ſquare of the time of one vibration.

9. The abſolute force or ſtrength of the balance ſpring, the time of one vibration, and the weight of the balance being the ſame, is inverſely as the ſquare of the diameter.

10. The weight of the balance, the ſtrength of the ſpring and time of vibration being the ſame, is inverſely as the ſquare of the diameter.

Hence, a large balance, vibrating in the ſame time with the ſame ſpring, will be much lighter than a ſmall one.

11. If the rim of the balance be always of the ſame breadth and thickneſs, ſo that the weight ſhall be as the radius, the ſtrength of the ſpring muſt be as the cube of the diameter of the balance, that the time of vibration may continue the ſame.

12. The momentum of the balance is increaſed better by increaſing its diameter than its weight.

13. The longer a detached balance continues its motion the better.

14. The greater the number of vibrations performed by a balance in a given time, the leſs ſuſceptible is it of external agitations.

15. Slow vibrations are, to a certain extent, preferable to quick vibrations: but there is manifeſtly a limit; for if the vibrations be too ſlow, the watch will be liable to ſtop.

16. A balance ſhould deſcribe as large arches as poſſible, as ſuppoſe 240°, 260°, 300°, or an entire circle.

Firſt, becauſe the momentum of the balance is thus increaſed; and therefore the inequalities in the force of the maintaining power bear a leſs proportion to it, and of conſequence will have leſs influence. 2dly. The balance is leſs ſuſceptible of external agitations. 3dly. A given variation in the extent of the vibrations produces a leſs variation in the going of the machine.

But care muſt be taken that in theſe great vibrations, the ſpring ſhall neither touch any obſtacle, nor its ſpires touch each other in contracting.

17. The time of the vibration of the balance is increaſed by heat, and diminiſhed by cold. Firſt, becauſe the length of the ſpiral ſpring is increaſed by heat, and therefore its force diminiſhed; and the contrary by cold. 2dly. The diameter of the balance is increaſed by heat, and therefore alſo the time of vibration; and the contrary by cold.

18. That balance is the moſt perfect which, without the compenſation of a thermometer, is moſt ſubject to the influence of heat and cold. Becauſe the obſtructions from oil and friction act as a compenſation to the expanſion or contraction of the ſpring and balance; therefore that balance which is moſt affected is moſt free from the influence of oil and friction.

19. The errors in the going of a watch, ariſing from the change of temperature, may be corrected by varying the length of the balance ſpring. Nevertheleſs, as it is extremely difficult to form an iſochronal ſpiral, any variation in its length is dangerous, becauſe we ſhall thus probably loſe that point which determines its iſochroniſm.

20. The errors in the going of a watch, occaſioned by the variation of temperature, may be corrected by varying the diameter of the balance.

This may be effected by a peculiar contrivance which has obtained the name of the *expanſion balance*, being compoſed of two different metals which poſſeſs different degrees of expanſibility, as braſs and ſteel, for inſtance; of which two metals it has been obſerved, that the increaſe of dimenſions by expanſion, in like elevations of temperature, is nearly as 2 to 1. For, according to Mr. Smeaton's experiments (vol. 48, Phil. Trans.), the correſponding expanſions of hard ſteel and braſs wire are as 147 and 232, the expanſions being occaſioned by a change from a medium temperature to that of 180° of Fahrenheit's thermometer. One of the moſt approved conſtructions of an expanſion balance, is exhibited in plate VII. and is thus deſcribed by Mr. Nicholſon: The outer part of the rim is braſs, and the inner ſteel. After this compound rim is brought to its figure by turning, it is cut through in three places, A, B, C, which ſets one end of each third part of the periphery at liberty to move outwards, when the temperature is diminiſhed, or inwards when it is increaſed. D, E, F, are three ſimilar and equal maſſes of metal, fitted upon the circular bars in a proper manner to admit of their being fixed at any required diſtance from the extremity, where the motion is moſt conſiderable. G, H, I, are three ſcrews, the heads of which may be ſet nearer to, or further from, the centre, and ſerve as weights to effect the adjuſtments for poſition and rate. The peculiar advantage of this balance may be explained as follows: when an increaſe of heat diminiſhes the elaſtic force of the pendulum ſpring K, the outer braſs rim being lengthened more than the ſteel, muſt throw the weights D, E, F, nearer to the axis, and diminiſh the effect of the inertia of the balance, which conſequently is as ſpeedily carried through its vibration as before. And on the contrary, when cold weather adds to the elaſtic force of the ſpring, the ſame weights are alſo thrown further out, and prevent the acceleration which would have followed. The exact adjuſtment of the weights is found by trial of the going of the machine: if it gain by heat, the weights do more than compenſate, and muſt be moved further from the extreme ends of the circular compound bars; but if the gain be produced by cold, the ſpring predominates, and the weights will accordingly require to be ſet further out.

BARK-MILL, a mill conſtructed for the purpoſe of grinding and preparing bark, till it is fit for the uſe of a tanner.

Bark-mills, like moſt other mills, are worked ſometimes by means of horſes, at others by water, and at others by wind. One of the beſt mills we have ſeen deſcribed for theſe purpoſes, is that invented by Mr. Bagnall, of Worſley in Lancaſhire: this machine will ſerve not only to chop bark, to grind, to riddle and pound it; but to beam, or work green hides and ſkins out of the maſtering or drench, and make them ready for the ouſe or bark liquor; to beam ſheepſkins and other ſkins for the ſkinner's uſe; and to ſcour and take off the bloom from tanned leather, when in the currying ſtate. The nature and connection of the different parts of this contrivance may be underſtood from the three figures on the right-hand ſide of plate VII. together with the following deſcription.

Fig. 1. is a horizontal plan of the mill. Fig. 2. longitudinal ſection of it. Fig. 3. tranſverſe ſection of it.

A, The water-wheel, by which the whole machinery is worked.

B, The ſhafts.

C, The pit-wheel, which is fixed on the water-wheel ſhaft B, and turns the upright ſhaft E, by the wheel F, and works the cutters and hammer by tapets.

D, The ſpur and bevil-wheel at the top of upright ſhafts.

E, The upright ſhaft.

F, The crown-wheel, which works in the pit-wheel C.

G, The ſpur-nut to turn the ſtones I.

P, The beam, with knives or cutters fixed at the end to chop or cut the bark; which bark is to be put upon the cutters or grating *i*, on which the beam is to fall.

Q, The tryal that receives the bark from the cutters *i*, and conveys it into the hopper H, by which it deſcends through the ſhoe J to the ſtones I, where it is ground.

K, The ſpout, which receives the bark from the ſtones, and conveys it into the tryal L; which tryal is wired to ſift or dreſs the bark, as it deſcends from the ſtones I.

M, The trough to receive the bark that paſſes through the tryal L.

R, The hammer, to cruſh or bruiſe the bark that falls into the diſh S, which ſaid diſh is on the incline, ſo that the hammer keeps forcing it out of the lower ſide of the ſaid diſh, when bruiſed.

k, A trough to receive the duſt and moſs that paſſes through the tryal Q.

T, The bevil-wheel, that works in the wheel D, which works the beam-knife by a crank V at the end of the ſhaft *u*.

W, The penetrating rod, which leads from the crank V to the ſtart *x*.

x, The ſtart, which has ſeveral holes in it to lengthen or ſhorten the ſtroke of the beam-knife.

y, The ſhaft, to which the ſlide rods *b*, *b*, are fixed by the ſtarts *n*, *n*,

b, The ſlide rod, on which the knife *f* is fixed; which knife is to work the hides, &c. On the knife are two ſprings *a*, *a*, to let it have a little play as it makes its ſtroke backwards and forwards, ſo that it may not ſcratch or damage the hides, &c.

z, Is a catch in ſlide-rod *b*, which catches on the arch-head and the ſaid arch-head conveys the knife back without touching the hide, and then falls back to receive the catch again.

l, The roller to take up the ſlide-rod *h*, while the hides are ſhifting on the beam *b* by pulling at the handle *m*.

b, The beam to work the hides, &c. on. Each beam has four wheels *p*, *p*, working in a trough road *g*, *g*, and removed by the levers *c*, *c*. When the knife has worked the hide, &c. ſufficiently in one part, the beam is then ſhifted by the lever *c* as far as is wanted.

d, A preſs, at the upper end of the beam, to hold the hide faſt on the beam while working.

e, An arch head, on which the ſlide-rod *h* catches.

f, The knife fixed on the ſlide-rod *h*, to work the hides, &c.

i, Cutters or grating to receive the bark for chopping.

The beam P, with knives or cutters, may either be worked by tapers, as deſcribed, or by the bevil-wheel T, with a crank, as V, to cut the ſame as ſhears.

The knife *f* is fixed at the bottom of the ſtart, which is fixed on the ſlide rod *h*; the bottom of the ſtart is ſplit open to admit the knife, the width of one foot; the knife ſhould have a gudgeon at each end, to fix in the open part of the ſtart; and the two ſprings *a*, *a*, prevent the knife from giving too much way when working; the knife ſhould be one foot long and four or five inches broad.

The arch-head *e* will ſhift nearer to, or further from, the beam *b*, and will be fixed ſo as to carry the knife back as far as is wanted, or it may be taken away till wanted.

The roller *l* is taken up by pulling at the handle *m*, which takes up the ſlide-rod ſo high as to give head-room under the beam-knife. The handle may be hung upon a hook for that purpoſe. The ſlide-rod will keep running upon the roller all the time the hide is ſhifting; and when the hide is fixed the knife is put on the beam again by letting it down by the handle *m*. There may be two or more knives at work on one beam at the ſame time, by having different ſlide-rods. There ſhould be two beams, ſo that the workmen could be ſhifting one hide, &c. while the other was working. The beam muſt be flat, and a little on the incline. As to the breadth it does not matter; the broader it is the leſs ſhifting of the hides will be wanted, as the lever *c* will ſhift them as far as the width of the hide, if required. Mr. Bagnall has formed a kind of preſs *d*, to let down, by a lever, to hold the hide faſt on each ſide of the knife if required, ſo that it will ſuffer the knife to make its back ſtroke without pulling the hide up as it comes back. The ſlide-rod may be weighted, to cauſe the knife to lay ſtreſs on the hide, &c. according to the kind and condition of the goods to be worked.

Hides and ſkins for the ſkinner's uſe are worked in the ſame way as for the tanners.

Scouring of tanned leather for the currier's uſe will be done on the beam, the ſame as working green hides. It is only taking the knife away, and fixing a ſtone in the ſame manner as the knife by the ſaid joint, and to have a bruſh fixed to go either before or after the ſtone. The leather will be better ſecured this way than by hand, and much ſooner.

The whole machinery may be worked by water, wind, ſteam, or any other power. And that part of the machinery which relates to the beaming part of the hides may be fixed to any horſe bark-mill, or may be worked by a horſe or other power ſeparately.

BARKER'S MILL is a kind of water-mill, invented by Dr. Barker, which without either wheel or trundle performs the operation of grinding corn. This mill is repreſented in fig. 3, pl. IV. in which A is a pipe or channel that brings water from a reſervoir to the upright tube. The water runs down the tube, and thence into the horizontal trunk C, which has equal arms; and, laſtly, runs out through holes at *d* and *e*, opening on contrary ſides near the ends of thoſe arms. Theſe orifices *d*, *e*, have ſliders fitted to them, ſo that their magnitude may be increaſed or diminiſhed at pleaſure.

The upright ſpindle D is fixt in the bottom of the trunk, and ſcrewed to it below by the nut *g*; and is fixt into the trunk by two croſs bars at *f*: ſo that, if the tube B and trunk C be turned round, the ſpindle D will be turned alſo.

The top of the ſpindle goes ſquare into the rynd of the upper mill-ſtone H, as in common mills; and as the trunk, tube, and ſpindle, turn round, the mill-ſtone is turned round thereby. The lower or quieſcent mill-ſtone is repreſented by I; and K is the floor on which it reſts, in which is the hole L to let the meal run through, and fall down into a trough which may be about M. The hoop or caſe that goes round the mill-ſtone reſts on the floor K, and ſupports the hopper, in the common way. The lower end of the ſpindle turns in a hole in the bridge-tree GF, which ſupports the mill-ſtone, tube, ſpindle, and trunk. This tree is moveable on a pin at *h*, and its other end is ſupported by an iron-rod N fixed into it, the top of the rod going through the firſt bracket O, and having a ſcrew-nut *o* upon it, above the bracket. By turning this nut forward or backward, the mill-ſtone is raiſed or lowered at pleaſure.

Whilſt the tube B is kept full of water from the pipe A, and the water continues to run out from the ends of the trunk; the upper mill-ſtone H, together with the trunk, tube, and ſpindle, turn round. But if the holes in the trunk were ſtopt, no motion would enſue; even though the tube and trunk were full of water. For, if there were no hole in the trunk, the preſſure of the water would be equal againſt all parts of its ſides within. But when the water has free egreſs through the holes, its preſſure there is entirely removed: and the preſſure againſt the parts of the ſides which are oppoſite to the holes turns the machine.

Mr. James Rumſey, an American gentleman, has rather improved this machine, by conveying the water from the reſervoir, not by a pipe as ADB, in great part of which the ſpindle turns, but by a pipe which deſcends from A, without the frame LN, till it reaches as low, or lower, than G; and then to be conveyed by a curvilinear neck and collar from G to *g*, where it enters the arms, as is ſhewn by the dotted lines at the lower part of the figure. A like improvement was made by M. Segner, a German.

Moſt of the authors who have attempted to lay down the theory of this mill have fallen into error: the moſt ingenious theory we have yet ſeen is by Mr. *Wm. Waring* (given in the *American Tranſactions*, vol. iii.); which, with ſome ſuch corrections as appeared neceſſary to adapt his rules to practical purpoſes, is nearly as follows:

1. The firſt enquiry relates to the *magnitude of the pipe* which conveys the water from the reſervoir to the centre of the horizontal tube *e d*, at *g*. To this end, let A = the area of the orifice by which the water is admitted at *g*; *h* = the perpendicular height of the ſurface of the water in the reſervoir above *g*; *d* = the vertical depth of any horizontal ſection of the pipe below the ſame ſurface; S = the ſurface or area of the horizontal ſection of the pipe, at the depth *d*. Then ſince the areas in the ſeveral parts of the pipe ſhould be inverſely as the velocities, and the velocities (art. 439, cor 2. vol. I.) are in the ſubduplicate ratio of the depths below the head, thoſe areas muſt be inverſely in the ſubduplicate ratio of the depths; conſequently, $\frac{S}{A}=\frac{\sqrt{h}}{\sqrt{d}}$, and $S = A\sqrt{\frac{h}{d}}$. So that the pipe muſt have its bore increaſed from the level of *g* upwards in the ratio of 1 to $\sqrt{\frac{h}{d}}$; and if a ſection in any part be leſs than would be aſſigned by this ratio, the water will be obſtructed in its paſſage.

2. *Of the initial force with which the machine commences its motion.* If we conceive the water preſſing in the tube from *g* towards *e*, previous to the opening of the aperture, there will manifeſtly be no motion occaſioned; becauſe the forces on the oppoſite ſides of the tube balance each other, and the force

againſt the end C is reſiſted by the fixed axle D g, or, if we conſider both arms, it is balanced by the equal force acting upon the equal end at d, in an oppoſite direction. But if one of the apertures, as d (its area being $=a$), is opened, the preſſure upon that portion of the tube is taken away, and the equal and oppoſite preſſure upon an equal portion of the contrary ſide of the tube, having now nothing to keep it in equilibrio, tends to move the arm C g about the axis D g: in like manner when the aperture e (alſo $=a$) is opened, the preſſure, which was previouſly counterbalanced by the oppoſite preſſure on the orifice e, now exerts its tendency to produce a rotatory motion about the axis D g: ſo that combining together the effects of both theſe unbalanced preſſures, and conſidering that the preſſure of water upon any point is proportional to the depth of that point below the upper ſurface of the fluid, we ſhall have $2\,a\,h\,w$, for the force which cauſes the rotatory motion to commence; the values of a and h being taken in feet, and w repreſenting $62\frac{1}{2}$ lbs. avoirdupois, the weight of a cubic foot of water. But as the velocity of rotation increaſes, the preſſure depending upon the relative velocities of the water and the ſides of the tube diminiſhes, and conſequently the power is diminiſhed, notwithſtanding what is gained by that which we now proceed to conſider.

3. *The centrifugal force.* This may be found in a ſimilar manner to that which was adopted when conſidering the theory of the centrifugal pump (art. 537, vol. i.). Thus, if beſides the preceding notation we take l for the length of each arm $g\,d$, $g\,e$, t for the time of rotation, g for $32\frac{1}{6}$ feet, the meaſure of the force of gravity, and π for 3·141593; ſince a is the ſection of the flowing water at right angles to its motion, we ſhall have, by proceeding as in the article juſt referred to, $\frac{2\pi^2 l^2}{g t^2}$ = the length of a column of water, whoſe preſſure is equal to the centrifugal force, or $\frac{4\pi^2 a w l^3}{g t^2} = 76{\cdot}70625\,\frac{a\,l^3}{t^2}$ the weight of a column of water in lbs., which is equivalent to the centrifugal force of the fluid in both arms. And this is equivalent to the augmentation of power at the apertures, becauſe fluids preſs equally in all directions.

4. *The inertia of the fluid* greatly counteracts the effects of the centrifugal force. The inertia of the rotatory tube with the contained fluid would not continue to reſiſt the moving power after the velocity became uniform, were the ſame fluid retained in it as was in it when the motion was firſt imparted: but as this paſſes off, and there is a continual ſucceſſion of new matter acquiring a motion in the direction of the rotatory, there muſt

be a conſtant re-action againſt the ſides of the tube, equal to the communicating force. Now this re-action is very different from that of a fluid confined in the tube, when it begins to move; becauſe a particle at the extremity of the tube is not to receive its whole circular motion there, but gradually acquires it by a uniform acceleration during its paſſage along the tube: ſo that we muſt here enquire what force will give to the quantity of water alw, in the time $\frac{l}{v}$ of its paſſing through its reſpective horizontal arm, the velocity $\frac{2\pi r}{t}$, in the direction of the aperture. Managing this according to the rules given for forces in the Dynamics, we ſhall have $\frac{12{\cdot}273\,alv}{t} \times \frac{8{\cdot}0208}{5} = 19{\cdot}6878\,\frac{alv}{t}$, for the reſiſtance in lbs. oppoſed to each arm, ſuch reſiſtance being eſtimated as if accumulated at the diſtance $\frac{1}{2}l$ from the centre of motion.

5. *Acquired velocity of the water.* According to the theory of Hydraulics, the velocity of water iſſuing through an aperture at the depth h below the upper ſurface of a reſervoir is expreſſed by $8{\cdot}0208\sqrt{h}$, which when reduced, in conformity with the experiments of Boſſut and others, becomes $5\sqrt{h}$ very nearly; and this is the velocity of the water paſſing out of the tubes at the commencement of the rotation. Then, as $\sqrt{2ahw} : 5\sqrt{h} ::$ $\sqrt{\left(2ahw + 76{\cdot}70625\,\frac{al^2}{t^2}\right)} : 5\sqrt{\left(h + 38{\cdot}35312\,\frac{l^2}{wt^2}\right)} = 5\sqrt{\left(h + {\cdot}61365\,\frac{l^2}{t^2}\right)} = v$, the acquired velocity of the water.

6. *Ratio of the central force to the inertia.* This will be aſcertained by ſubſtituting for v in the expreſſion $19{\cdot}6878\,\frac{alv}{t}$, its value juſt found; ſo that we have $98{\cdot}439\,\frac{al^2}{t^2} \times \sqrt{\left({\cdot}61365 + \frac{ht^2}{l^2}\right)}$ for the inertia, while the centrifugal force is meaſured by $76{\cdot}70625\,\frac{al^2}{t^2}$. Now we find that $76{\cdot}70625\,\frac{al^2}{t^2} : 98{\cdot}439\,\frac{al^2}{t^2} \times \sqrt{\left({\cdot}61365\,\frac{ht^2}{l^2}\right)} :: 1 : 1{\cdot}2833\sqrt{\left({\cdot}61365\,\frac{ht^2}{l^2}\right)}$, or as $1 : \sqrt{(1}$

$+\frac{1\cdot646\,h\,t^2}{l^2})$ very nearly; which is the ratio of the power gained by the centrifugal force to the obſtruction ariſing from inertia. Whence it appears that the latter is greater than the former, except when $t=0$, $h=0$, or $l=\infty$, caſes never occurring in practice; and that the longer the arms, the leſs the fall of water, and the greater the velocity of rotation, the nearer theſe forces approach to the ratio of equality.

6. *Adjuſtment of the parts and motion.* Here it muſt be particularly obſerved, that the centrifugal force ſhould not exceed the gravity of the water revolving in the arms $g\,d$, $g\,e$; for in that caſe the water would be drawn into the tube faſter than it could be naturally ſupplied at its entrance, by the velocity proper to that depth, and of conſequence a vacuum muſt be occaſioned: nor ſhould the velocity of the apertures be greater than half that of the water through them; for the apertures being ſtill adapted in point of magnitude to the velocity, the effluent quantity or number of acting particles is as the time, the momentum is in the ſimple ratio of the relative velocity, and therefore (art. 472, cor. 3, vol. i.) the greateſt effect will be produced when the velocity of the apertures is equal to half that due to the head of water. Theſe two conditions expreſſed algebraically will furniſh the equations,

$$76\cdot70625\,\frac{a\,l^2}{t^2} = 2\,a\,l\,w \ldots \frac{2\,\pi\,l}{t} = \tfrac{5}{2}\sqrt{h+l}:$$

from which eqnations we deduce the following,

$$\text{viz.}\begin{cases} h = 9\cdot29345\,l = 15\cdot1446\,t^2 \\ l = 1\cdot6296\,t^2 = \cdot1076\,h \\ t = \sqrt{\cdot61365\,l} = \sqrt{\cdot06603\,h} \end{cases}$$

Whence it appears that h, l, and t^2, are nearly in the conſtant ratio of 15, 9¼, and 1.

Still it ſhould be obſerved that while l and t are preſerved in a conſtant ratio, the values of $76\cdot70625\,\frac{a\,l^2}{t^2}$, and of $12\cdot273\,\frac{a\,l\,v}{t}$, i. e. of the central force and of the inertia muſt remain the ſame: ſo that the brachia may be made of any length at pleaſure (not leſs than $\cdot1076\,h$) if the time of revolution be taken in a correſponding proportion, or ſo that the velocity of the apertures undergo no variation, which will be enſured by making $t = \sqrt{\cdot61365\,l}$: for a double or triple radius, revolving in a double or triple time, or with half or a third the angular velocity, has the ſame abſolute velocity at the extremity; and, with the ſame power there applied, will produce the ſame effect. Hence,

7. *The moving force and velocity of the machine, when the effect is a maximum,* may be found. For, if we put $\cdot61365\,l$ for t^2,

and 9·29345 l for b, in the expreſſion $\sqrt{\left(1 + \frac{1{\cdot}646\,h\,t^2}{l^2}\right)}$ it becomes $\sqrt{1 + 3} = 2$; in which caſe the reſiſtance of inertia is juſt double the central force, or the gravity of the water in the tube $= 125\,a\,l$, which taken from the impelling force leaves $62{\cdot}5\,(a\,b + l) - 125\,a\,l = 62{\cdot}5\,a\,(b - l) = 55{\cdot}775\,a\,b$ lbs. avoirdupois = the real moving force, at the diſtance of the centres of the apertures from the centre of motion, l being taken $= {\cdot}1076\,b$. And by a like ſubſtitution the velocity $\frac{5}{2}\sqrt{b + l}$, becomes $\frac{5}{2}\sqrt{1{\cdot}1076\,b} = 2{\cdot}63205\,\sqrt{b}$, feet per ſecond.

8. *Area of the apertures.* If $A =$ the area of a ſection of the race perpendicular to the direction of its motion, $V =$ its velocity per ſecond, both in feet, a and b as before; then it will be $AV = 10\,a\sqrt{\left(b + {\cdot}61365\frac{l^2}{t^2}\right)}$ cubic feet = the quantity of water emitted per ſecond, by both apertures: hence $a = \frac{AV}{14{\cdot}2722\sqrt{h}} = \frac{{\cdot}070066\,AV\sqrt{h}}{h}$, the area proper for one of the apertures.

From the preceding inveſtigation we may deduce the following

Eaſy practical rules.

1. Make each arm of the horizontal tube, from the centre of motion to the centre of the aperture, of any convenient length, not leſs than $\frac{1}{9}$ of the perpendicular height of the water's ſurface above theſe centres.

2. Multiply the length of the arm in feet, by ·61365, and take the ſquare root of the product for the proper time of a revolution in ſeconds; and adapt the other parts of the machinery to this velocity: or,

3. If the time of a revolution be given, multiply the ſquare of this time by 1·6296 for the proportional length of the arm in feet.

4. Multiply together the breadth, depth, and velocity per ſecond of the race, and divide the laſt product by 14·27 times the ſquare root of the height, for the area of either aperture: or, multiply the continual product of the breadth, depth, and velocity, of the race, by the ſquare root of the height, and by the decimal ·07; the laſt product, divided by the height, will give the area of the aperture.

5. Multiply the area of either aperture by the height of the head of water, and the product by 55·775 (or 56 lbs), for the moving force, eſtimated at the centres of the apertures in pounds avoirdupois.

6. The power and velocity at the apertures may be eaſily reduced to any part of the machinery, by well-known rules.

BAROMETER, a well-known inſtrument for meaſuring the weight or preſſure of the atmoſphere, and the variations that happen therein, in order to indicate the changes in the weather, or the changes in vertical diſtance from any point upon the earth's ſurface.

We ſhall here deſcribe a few of the moſt uſeful conſtructions of the barometer, and ſhall begin with

The Common Barometer. This is repreſented at fig. 1. plate VII. ſuch as it was invented by Torricelli. AB is a glaſs tube, of $\frac{1}{4}$, or $\frac{1}{3}$, or $\frac{1}{2}$ inch wide, the more the better, and about 34 inches long, being cloſe at the top A, and the open end B immerſed in a baſin of quickſilver CD, which is the better the wider it is. To fill this, or any other barometer, take a clean new glaſs tube, of the dimenſions as above, and pour into it well-purified quickſilver, with a ſmall funnel either of glaſs or paper, in a fine continued ſtream, till it wants about half an inch or an inch of being full; then, ſtopping it cloſe with the finger, invert it ſlowly, and the air in the empty part will aſcend gradually to the other end, collecting into itſelf ſuch other ſmall air bubbles as unavoidably get into the tube among the mercury, in filling it with the funnel: and thus continue to invert it ſeveral times, turning the two ends alternately upwards, till all the air bubbles are collected, and brought up to the open end of the tube, and till the part filled ſhall appear, without ſpeck, like a fine poliſhed ſteel rod. This done, pour in a little more quickſilver, to fill the empty part quite full, and ſo exclude all air from the tube: then, ſtopping the orifice again with the finger, invert the tube, and immerſe the finger and end, thus ſtopped, into a baſin of like purified quickſilver. In this poſition withdraw the finger; ſo ſhall the mercury deſcend in the tube to ſome place, as H, between 28 and 31 inches above that in the baſin at F, as theſe are the limits between which it always ſtands in this country on the common ſurface of the earth. Then meaſure, from the ſurface of the quickſilver in the baſin at F, 28 inches to K and 31 inches to L, dividing the ſpace between them into inches and tenths, which are marked on a ſcale placed againſt the ſide of the tube; and the tenths are ſubdivided into hundredth parts of an inch by a ſliding index carrying a vernier or nonius. Theſe 3 inches, between 28 and 31, ſo divided, will anſwer for all the ordinary purpoſes of a ſtationary or chamber barometer; but for experiments on altitudes and depths it is proper to have the diviſions carried on a little higher up, and a great deal lower down. In the proper filling and otherwiſe fitting up of the barometer, ſeveral circumſtances are to be carefully noted; as, that the bore of the tube be pretty wide, to allow the freer motion of the quickſilver, without being impeded by an adheſion to the ſides; that the baſin below it be alſo pretty large, in order that the ſurface of the mercury at F may not ſenſibly riſe or fall with that in the tube; that the bottom of the tube be cut off rather obliquely, ſo that when it reſts on the bottom of the baſin there may be a free paſſage for the quickſilver; and that, to have the quickſilver very pure, it is beſt to boil it in the tube, which will expel all the air from it. This barometer is commonly fitted up in a neat mahogany caſe, together with a thermometer and hygrometer.

2. As the ſcale of variation is ſmall in the common barometer, being not more than 3 inches, ſeveral contrivances have been deviſed to enlarge the ſcale, or to render the motion of the quickſilver more perceptible. Among the beſt of theſe is that known by the name of *Diagonal Barometer*, and is repreſented in fig. 2. where ABC is a tube hermetically ſealed at C, and immerſed in a baſin of mercury at A. This tube is perpendicular from A to B, where the ſcale of variation begins; but is there bent into the form BC, making an acute angle FBC. This part BC extends to the higheſt limit in the ſcale of variation, viz. IC; and conſequently while the mercury riſes from K to I, in the common barometer, it will move in this from B to C, enlarging the ſcale of variation in the proportion of BC to FB; that is, of the diagonal to the leaſt ſide of the parallelogram.

But this barometer is attended with one great inconvenience, which leſſens its utility. Quickſilver being a very heavy body, and ſupported on the part BC, forming an inclined plane, it muſt have a very conſiderable degree of friction, which will be increaſed in proportion as the part BC is more oblique; and conſequently the very ſmall and nice variation of the air's preſſure cannot be ſo accurately indicated in this as in the common form. It alſo very often happens, from the inclination of the part BC, that the quickſilver divides into ſeveral parts, and thence frequently requires the trouble of re-filling the tube. This barometer was invented by Sir Samuel Moreland.

3. Caſſini invented another kind of barometer, in order to enlarge the ſcale of variation; an invention which was afterwards completed by M. John Bernoulli. It conſiſts of a tube ACDF (fig. 3.) hermetically ſealed at A, and bent to a right angle at D; whence it has acquired the name of the horizontal rectangular barometer. The mercury ſtands in both the legs from E to B; the ſcale of variation from A to C is made in a larger part; and it is evident, that in moving three inches from

A to C it will move through ſo many times three inches in the ſmall leg DF as the bore of DF is leſs than the bore of AC; whence the motion of the mercury at E muſt be extremely ſenſible. But the inconvenience here too is, that the mercury is very apt to break off in the leg E, and alſo to run out at the end E. Here is alſo a great degree of friction, and at the ſame time the attraction of coheſion will, from the ſmallneſs of the bore DF, impede the free motion of the mercury.

4. *The Pendant Barometer* is made in another form, conſiſting of a ſingle tube ſuſpended by a ſtring faſtened to the end A (fig. 4.). This tube is of a conical or tapering form, the end A being a *little* leſs than that at B. It is hermetically ſealed at A, and filled with mercury: then will the mercury ſink to its common ſtation, and admit a length of altitude CD, the ſame with that in the common barometers. But, from the conical bore of the tube, the mercury will deſcend as the air becomes lighter, till it reaches its loweſt altitude, when the mercury will ſtand from the loweſt part of the tube B to E; ſo that BE = 28 inches: and conſequently the mercury will, in ſuch a tube, move from A to E, or 32 inches, if the tube be five feet long; ſo that the ſcale AE may here be made more than 10 times greater than that of the common barometer. The inconvenience attending this barometer is, that as the tube muſt be made of a very ſmall bore, to prevent the mercury from falling out by an accidental ſhake, the friction and adheſion to the ſides of the tube prevent that freedom of motion neceſſary to ſhew a very ſmall variation in the weight of the air.

5. Mr. Rowning had ſeveral contrivances for enlarging the ſcale, and that in any proportion whatever. One of theſe is deſcribed in No. 427. Phil. Trans. and has now obtained the name of *Rowning's Barometer*: it is repreſented at fig. 5. where ABC is a compound tube, hermetically ſealed at A, and open at C; empty from A to D, filled with mercury from thence to B, and thence to E with water. Here, by varying the proportions of the two tubes AF and FC, the ſcale of variation may be changed in any degree.

6. *Dr. Hooke's Wheel Barometer* was invented about 1668, and is likewiſe intended to render the alterations in the ſtate of the air more perceptible. Here the barometer tube has a large ball AB at the top (fig. 9. pl. VII.), and is bent up at the lower or open end, where an iron ball, G, floats on the top of the mercury in the tube, to which is connected another ball, H, by a cord, hanging freely over a pulley, turning an index KL about its centre. When the mercury riſes in the part FG it raiſes the ball, and the other ball deſcends and turns the pulley with the index round a graduated circle from N towards M and P; and the contrary way when the quickſilver and the ball ſink in the

bent part of the tube. Hence the ſcale is eaſily enlarged ten or twelve fold, being increaſed in proportion as the length of the index exceeds the radius of the pulley. But then the friction of the pulley and axis greatly obſtructs the free motion of the quickſilver. Contrivances to leſſen the friction are deſcribed in Phil. Trans. vol. 52 and 60. In Nicholſon's Journal, No. 9, New Series, the rev. James Wilſon has deſcribed a method of increaſing the ſenſibility of the barometer, *ad libitum*, which is very ingenious; but need not be inſerted here: for this, and all contrivances, having the ſame end in view, are not ſuperior, but often inferior, to the common barometer, for all philoſophical purpoſes; and that for a reaſon which admits of no reply. Their ſcale muſt be determined in all its parts by that of the common barometer; and, therefore, notwithſtanding their great range, they are ſuſceptible of no greater accuracy than that with which the common barometer can be obſerved and meaſured. And beſides this, theſe compound barometers have an additional ſource of error, in the action of coheſion, the operation of friction, &c. So that, except (perhaps) for mere chamber purpoſes, the common conſtruction of the barometer, with a nonius applied to its ſcale, is greatly preferable; and our attention ſhould be entirely directed to its improvement and portability.

7. This leads us to ſpeak of the conſtruction of a *portable Barometer*, which may be carried from one place to another without being rendered unfit for uſe; and is, therefore, ready to be adopted at all times in the menſuration of altitudes, &c. In this barometer the end of the tube is tied up in a leathern bag, not quite full of mercury; which being preſſed by the air forces the mercury into the tube, and keeps its ſuſpended at its height. This bag is uſually encloſed in a box, through the bottom of which paſſes a ſcrew, by whoſe means the mercury may be forced up to the top of the tube, and prevented from breaking it by daſhing againſt the top when the inſtrument is removed from one ſtation to another. Mr. Patrick was, we believe, the firſt who made a contrivance of this kind; but the portable barometer has received various improvements ſince by M. de Luc, Sir Geo. Shuckburgh, Col. Roy, Mr. Ramſden, and others. Fig. 8. pl. VII. repreſents this inſtrument as encloſed in its mahogany caſe by means of three metallic rings *b*, *b*, *b*. This caſe is a hollow cone, ſo ſhaped within as ſteadily to contain the body of the barometer, and is divided into three branches from *a* to *c*, forming three legs or ſupports for the inſtrument when obſervations are making, and ſuſtaining it at the part *g* of the caſe; by an improved kind of gimbals, as it appears in fig. 7. in which its own weight renders it ſufficiently

ſteady at any time. In the part of the frame *a g* where the barometer tube appears a long ſlit or opening is made, ſo that the column of mercury may be ſeen againſt the light, and the vernier piece, *a*, brought down to coincide very nicely with the edge of the mercury. When the inſtrument is fixed in its ſtand, the ſcrew, *f*, is to be turned to let the mercury down to its proper poſition, and a peg at *p* muſt be looſened, in order that the external air may be admitted to act upon the mercury contained in the box *b*. The proper adjuſtment or mode of obſerving the *zero* or o diviſion of the column of mercury is by obſerving it in the tranſparent part of the box *b*, which has a glaſs reſervoir for the quickſilver, and an edged piece of metal attached to the external part of it; with the edge of which the mercury is to be brought into contact, by turning the ſcrew *f* to the right or left, as occaſion requires. The vernier piece at *a*, which determines the altitude of the mercurial column, is firſt brought down by the hand to a near contact, and then accurately adjuſted by turning the ſcrew *h* at the top. The diviſions annexed to the tube of this inſtrument may be of any kind, or of any degree of minuteneſs, according to the purpoſe it is intended to ſerve. To accommodate it to the uſe of foreigners as well as the Engliſh, there are commonly added ſcales of both French and Engliſh inches, with the requiſite ſubdiviſions. It is uſual to place the French ſcale of inches on the right ſide, at *a g* from 19 to 31 inches, meaſured from the zero or ſurface of the mercury in the box *b*; each inch being divided into lines or 12th parts, and each line ſubdivided by the vernier into 10th parts: ſo that the length of the mercurial column may be determined to the 120th part of a French inch. The other ſcale, which is placed on the left ſide of the inſtrument, is divided into 20th parts of inches, and theſe again into 25th parts by means of the vernier; thus meaſuring to 500ths of an Engliſh inch: and the diviſions on the vernier ſcale are marked double what they really are, in order that the meaſures may be expreſſed in thouſandth parts of an inch, for the convenience of calculation.

To this inſtrument a thermometer is always attached, as a neceſſary appendage; being faſtened to the body at *c*, and ſunk into the ſurface of the frame to preſerve it from injury: the degrees of this thermometer are generally marked ſo as to indicate the diviſions both of Fahrenheit's and of Reaumur's ſcale. (See THERMOMETER.) Alſo on the right-hand of theſe two ſcales is a third, called ſcale of *correction*, with the words *add* and *ſubtract* marked; thus ſerving to ſhew the neceſſary correction of the obſerved altitude of the mercury, at any given temperature of the air indicated by the thermometer.

Several minutiæ in the mechanical conſtruction of this inſtrument will be more obvious from a few minutes' inſpection than by any further details here. The rules for its uſe in the aſcertaining of altitudes may be learnt by turning to the theoretic part of this work: book iv.

BEAM COMPASSES. See COMPASSES.

BEER-DRAWING MACHINES are contrivances by means of which the beer is drawn from three or four caſks at once, from cocks ſtanding in one frame, in the bar of a tavern, or any convenient place above a cellar. Theſe machines are nothing elſe than an aſſemblage of ſmall pumps, either ſucking or forcing, whoſe pipes of communication are attached to the lower parts of the reſpective caſks from which the liquor is drawn. The motion is given to the piſton ſometimes by levers, at others by cranks; moſt frequently, we believe, by means of a hammer-formed lever moving in a vertical plane.

BELLOWS, an inſtrument conſtructed for the purpoſe of alternately drawing and expelling air In the common culinary bellows the air ruſhes in at a hole or holes in the bottom, called feeders, over which is a flapping valve, and is expelled through a conical pipe called the nozzle, by means of a kind of mechaniſm which is too well known to need any deſcription here.

It is not the impulſive force of the blaſt that is wanted in moſt caſes, but merely the copious ſupply of air to produce the rapid combuſtion of inflammable matter; and the ſervice would, in general, be better performed if this could be done with moderate velocities and an extended ſurface. What are called air-furnaces, where a conſiderable ſurface of inflammable matter is acted on at once by the current which the mere heat of the expended air has produced, are found more operative, in proportion to the air expended, than blaſt-furnaces animated by bellows. There is, indeed, a great impulſive force required in ſome caſes; as, for blowing off the ſcoriæ from the ſurface of ſilver or copper in refining furnaces, or for keeping a clear paſſage for the air in great iron ſurfaces. But in general we cannot procure this abundant ſupply of air in any other way than by giving it a great velocity by means of a great preſſure or impulſe; the air is admitted into a very large cavity, and then forcibly expelled from it through a ſmall orifice.

The method of producing a continual blaſt by a centrifugal force has been long known, being mentioned by *Agricola de Re Metallica*, lib. 6. p. 62. But the firſt bellows acting upon this principle, of which we recollect a diſtinct account amongſt the moderns, is that invented by M. *Teral*, in 1729, and deſcribed in the *Recueil des Machines approuvées par L'Academie*

Roy. des Sciences, tome 5. This machine is repreſented in fig. 7. pl. VIII. where AB is a cubical box, with a top rather arched: to this box is adapted a hollow pyramidal fruſtrum C, at the extremity of which is the tube or nozzle D; the capacity of the pyramid not being ſeparated from that of the box. This box contains an arbor or ſhaft carrying vanes, as GF, poſited horizontally, and which are here placed, as it were, out of the box, that their ſhape and number may be ſeen. The ends of the arbor run in a proper collar on each ſide of the box, and one end, as F, paſſes through the ſide of the box, and carries a pulley: over this pulley paſſes a cord or band, which alſo runs round part of a wheel HI, ſituated at ſome diſtance from the bellows, and which is turned by the handle M. Thus it will be manifeſt, that as this handle turns the wheel HI, it will, by means of the band, turn the pulley F and the arbor and vanes, with a velocity which will be to that of the wheel as the radius of the wheel to that of the pulley. Hence the greater the diameter of the wheel, and the leſs that of the pulley, the more rapidly will the exterior air (which enters by ſmall holes *h h*, into the top of the box) be driven by the vanes, and compreſſed into the truncated pyramid *c*, and thence expelled at D, in a continued blaſt; which will likewiſe be the more violent the greater the action at the handle M. This machine, being very ſimple, is eaſily conſtructed, and at a ſmall expence.

Another bellows, furniſhing a uniform blaſt, is deſcribed in the article PNEUMATICS, *Encyclopædia Britannica*, as below: one cylinder is made to deliver its air into another cylinder, which has a piſton exactly fitted to its bore, and loaded with a ſufficient weight. The blowing cylinder ABCD (fig. 3. pl. VIII.) has its piſton P worked by a rod NP, connected by double chains with the arched head of the working beam NO, moving round a gudgeon at R. The other end O of this beam is connected by the rod OP with the crank PQ of a wheel machine; or it may be connected with the piſton of a ſteam-engine, &c. &c. The blowing cylinder has a valve or valves E in its bottom, opening inwards. There proceeds from it a large pipe CF, which enters the regulating cylinder GHKI, and has a valve at top, to prevent the air from getting back into the blowing cylinder. It is evident that the air forced into this cylinder muſt raiſe its piſton L, and that it muſt afterwards deſcend, while the other piſton is riſing. It muſt deſcend uniformly, and make a perfectly equable blaſt.

Obſerve, that if the piſton L be at the bottom when the machine begins to work, it will be at the bottom at the end of every ſtroke, if the *tuyere* T emits as much air as the cylinder ABCD furniſhes; nay, it will lie a while at the bottom; for, while it was riſing, air was iſſuing through T. This would make an interrupted blaſt. To prevent this, the orifice T muſt be leſſened; but then there will be a ſurplus of air at the end of each ſtroke, and the piſton L will riſe continually, and at laſt get to the top, and allow air to eſcape. It is juſt poſſible to adjuſt circumſtances, ſo that neither ſhall happen. This is done eaſier by putting a ſtop in the way of the piſton, and putting a valve on the piſton, or on the conducting pipe KST, loaded with a weight a little ſuperior to the intended elaſticity of the air in the cylinder. Therefore, when the piſton is prevented by the ſtop from riſing, the ſhifting valve, as it is called, is forced open, the ſuperfluous air eſcapes, and the blaſt preſerves its uniformity.

The Hydraulic Forge Bellows, of Mr. J. C. Hornblower, is a very ingenious contrivance, and is, therefore, deſcribed here. This invention is ſhewn in plate V.

A. The plunger, or working part of the bellows, 18 inches ſquare within, which receives the air by a valve in the hinder part opening inwards, which at the ſtroke by the rockſtaff E throws it down the tube indicated by the dotted lines, which has a valve opening into the reſervoir D, whence it is led to the tuyere by the pipe P. Length of the plunger 20 inches, ſtroke nine inches. Diameter of P three inches; of the nozzle 0·6.

The whole is placed in a pit or ciſtern, having water ſufficient to riſe to the lower end of the tube where the valve hangs; this tube is the only communication between the upper part and the reſervoir D: when as much water is poured in round the working part, over the waſh-boards, as will riſe within five inches of the upper edge of them, the bellows is ready for uſe. The little frame-work ſerves to keep it from riſing, and affords a convenient ſupport for the balance and the rockſtaff. The area of the pit or ciſtern ought to be at leaſt twice as much as that of the plunger A.

Mr. Hornblower mentions a very ſtriking difference between the effect of this bellows and a common leathered 30-inch bellows in the ſame ſhop. The leathered bellows throws conſiderably more air to the fire, and its nozzle compared with this is as ·73 to ·60 in diameter, but it does not produce ſo great an effect in bringing on the heat, and the voice of this is ſo great as almoſt to drown that of the common one. The only difference in other reſpects is, that in the hydraulic bellows the pipe goes underground for about eight feet, and the conducting pipe of the other comes down about the ſame diſtance from the ſhop above. *Nicholſon's Jour. N. S. vol.* I.

BORING *of Cylinders, Ordnance, Wooden Pipes*, &c, See CYLINDERS, ORDNANCE, and PIPES.

BRAMAH'S MACHINE, *Bramah's Hydroſtatic Preſs*, &c.—names which are now commonly given to the contrivances of Mr. Bramah of Piccadilly, by which he applied the *quaqua verſum* preſſure of fluids as a very powerful agent in many kinds of machinery requiring motion and force. Theſe contrivances (for which Mr. Bramah took out a patent in March 1796) conſiſt in the application of water, or other denſe fluids, to various engines, ſo as, in ſome inſtances, to cauſe them to act with immenſe force; in others, to communicate the motion and powers of one part of a machine to ſome other part of the ſame machine; and, laſtly, to communicate the motion and force of one machine to another, where their local ſituations preclude the application of all other methods of connection.

The firſt and moſt material part of this invention will be clearly underſtood by an inſpection of fig. 4. pl. IX. where "A is a cylinder of iron, or other materials, ſufficiently ſtrong, and bored perfectly ſmooth and cylindrical; into which is fitted the piſton B, which muſt be made perfectly water-tight, by leather or other materials, as uſed in pump-making. The bottom of the cylinder muſt alſo be made ſufficiently ſtrong with the other part of the ſurface, to be capable of reſiſting the greateſt force or ſtrain that may at any time be required. In the bottom of the cylinder is inſerted the end of the tube C; the aperture of which communicates with the inſide of the cylinder, under the piſton B, where it is ſhut with the ſmall valve D, the ſame as the ſuction-pipe of a common pump. The other end of the tube C communicates with the ſmall forcing-pump or injector E, by means of which water or other denſe fluids can be forced or injected into the cylinder A, under the piſton B. Now, ſuppoſe the diameter of the cylinder A to be 12 inches, and the diameter of the piſton of the ſmall pump or injector E only one quarter of an inch, the proportion between the two ſurfaces or ends of the ſaid piſtons will be as 1 to 2304; and ſuppoſing the intermediate ſpace between them to be filled with water or other denſe fluid capable of ſufficient reſiſtance, the force of one piſton will act on the other juſt in the above proportion, viz. as 1 is to 2304. Suppoſe the ſmall piſton in the injector to be forced down when in the act of pumping or injecting water into the cylinder A, with the power of 20 cwt. which could eaſily be done by the lever H; the piſton B would then be moved up with a force equal to 20 cwt. multiplied by 2304. Thus is conſtructed a hydro-mechanical engine, whereby a weight amounting to 2304 tons can be raiſed by a ſimple lever, through equal ſpace, in much leſs time than could be done by any apparatus conſtructed on the known principles of mechanics; and it may be proper to obſerve, that the effect of all other mechanical combinations is counteracted by an accumulated complication of parts, which renders them incapable of being uſefully extended beyond a certain degree; but in machines acted upon or conſtructed on this principle every difficulty of this kind is obviated, and their power ſubject to no finite reſtraint. To prove this, it will be only neceſſary to remark, that the force of any machine acting upon this principle can be increaſed *ad infinitum*, either by extending the proportion between the diameter of the injector and the cylinder A, or by applying greater power to the lever H.

"Fig. 5. repreſents the ſection of an engine, by which very wonderful effects may be produced inſtantaneouſly by means of compreſſed air. AA is a cylinder, with the piſton B fitting air-tight, in the ſame manner as deſcribed in fig. 4. C is a globular veſſel made of copper, iron, or other ſtrong materials, capable of reſiſting immenſe force; ſimilar to thoſe of air-guns. D is a ſtrong tube of ſmall bore, in which is the ſtop-cock E. One of the ends of this tube communicates with the cylinder under the piſton B, and the other with the globe C. Now, ſuppoſe the cylinder A to be the ſame diameter as that in fig. 4. and the tube D equal to one quarter of an inch diameter, which is the ſame as the injector fig. 4.: then, ſuppoſe that air is injected into the globe C (by the common method), till it preſſes againſt the cock E with a force equal to 20 cwt. which can eaſily be done; the conſequence will be, that when the cock E is opened the piſton B will be moved in the cylinder AA with a power or force equal to 2304 tons; and it is obvious, as in the caſe fig. 4. that any other unlimited degree of force may be acquired by machines or engines thus conſtructed.

"Fig. 6. is a ſection, merely to ſhew how the power and motion of one machine may, by means of fluids, be transferred or communicated to another, let their diſtance and local ſituation be what they may. A and B are two ſmall tubes, ſmooth and cylindrical; in the inſide of each of which is a piſton, made water and air-tight, as in figs. 4. and 5. CC is a tube conveyed under ground, or otherwiſe, from the bottom of one cylinder to the other, to form a communication between them, notwithſtanding their diſtance be ever ſo great; this tube being filled with water or other fluid, until it touch the bottom of the piſton; then, by depreſſing the piſton A, the piſton B will be raiſed. The ſame effect will be produced *vice verſa*: thus bells may be rung, wheels turned, or other machinery put inviſibly in motion, by a power being applied to either.

"Fig. 7. is a ſection, ſhewing another inſtance of communicating the action and force of one machine to another; and how water may be raiſed out of wells of any depth, and at any diſtance from the place where the operating power is applied. A is a cylinder of any required dimenſions, in which is the working piſton B, as in the foregoing examples: into the bottom of this cylinder is inſerted the tube C, which may be of leſs bore than the cylinder A. This tube is continued, in any required direction, down to the pump cylinder D, ſuppoſed to be fixed in the deep well EE, and forms a junction therewith above the piſton F; which piſton has a rod G, working through the ſtuffing-box, as is uſual in a common pump. To this rod G is connected, over a pulley or otherwiſe, a weight H, ſufficient to overbalance the weight of the water in the tube C, and to raiſe the piſton F when the piſton B is lifted: thus, ſuppoſe the piſton B is drawn up by its rod, there will be a vacuum made in the pump cylinder D, below the piſton F; this vacuum will be filled with water through the ſuction pipe, by the preſſure of the atmoſphere, as in all pumps fixed in air. The return of the piſton B, by being preſſed downwards in the cylinder A, will make a ſtroke of the piſton in the pump cylinder D, which may be repeated in the uſual way by the motion of the piſton B, and the action of the water in the tube C. The rod G of the piſton F, and the weight H, are not neceſſary in wells of a depth where the atmoſphere will overbalance the water in the ſuction of the pump cylinder D, and that in the tube C. The ſmall tube and cock in the ciſtern I are for the purpoſe of charging the tube C."

By theſe means it is obvious moſt commodious machines of prodigious power, and ſuſceptible of the greateſt ſtrength, may readily be formed. If the ſame multiplication of power be attempted by toothed wheels, pinions, and racks, it is ſcarcely poſſible to give ſtrength enough to the teeth of the racks, and the machine becomes very cumberſome and of great expence. But Mr. Bramah's machine may be made abundantly ſtrong in very ſmall compaſs. It only requires very accurate execution. Mr. Bramah, however, is greatly miſtaken when he publiſhes it as the diſcovery of a *new* mechanic power. The principle on which it depends has been *well known* for nearly two centuries; and it is matter of ſurpriſe that it has never before been applied to any uſeful practical purpoſe.

CAMEL is the name given to a machine employed by the Dutch for carrying veſſels heavily laden over the ſand-banks in the Zuyder-Zee. In that ſea, oppoſite to the mouth of the river Y, about ſix miles from the city of Amſterdam, there are two ſand-banks, between which is a paſſage called the Pampus, ſufficiently deep for ſmall veſſels, but not for thoſe which are large and heavily laden. On this account ſhips which are outward bound take in before the city only a ſmall part of their cargo, receiving the reſt when they have got through the Pampus. And thoſe that are homeward bound muſt, in a great meaſure, unload before they enter it. For this reaſon the goods are put into lighters, and in theſe tranſported to the warehouſes of the merchants in the city; and the large veſſels are then made faſt to boats, by means of ropes, and in that manner towed through the paſſage to their ſtations.

Though meaſures were adopted ſo early as the middle of the ſixteenth century, by forbidding ballaſt to be thrown into the Pampus, to prevent the further accumulation of ſand in this paſſage, that inconvenience increaſed ſo much from other cauſes as to occaſion ſtill greater obſtruction to trade; and it at length became impoſſible for ſhips of war, and others heavily laden, to get through it. About the year 1672 no other remedy was known than that of making faſt to the bottoms of ſhips large cheſts filled with water, which was afterwards pumped out; ſo that the ſhips were buoyed up, and rendered ſufficiently light to paſs the ſhallow. By this method, which was attended with the utmoſt difficulty, the Dutch carried out their numerous fleet to ſea in the abovementioned year. This plan, however, gave riſe ſoon after to the invention of the camel, by which the labour was rendered eaſier.

The camel conſiſts of two half ſhips, conſtructed in ſuch a manner that they can be applied below water, on each ſide of the hull of a large veſſel. On the deck of each part of the camel are a great many horizontal windlaſſes, from which ropes proceed through apertures in the one half, and, being carried under the keel of the veſſel, enter ſimilar apertures in the other, from which they are conveyed to the windlaſſes on its deck. When they are to be uſed, as much water as may be neceſſary is ſuffered to run into them; all the ropes are caſt looſe, the veſſel is conducted between them, and large beams are placed horizontally through the port-holes of the veſſel, with their ends reſting on the camel on each ſide. When the ropes are made faſt, ſo that the ſhip is ſecured between the two parts of the camel, the water is pumped from them; by which means they riſe, and raiſe the ſhip along with them. Each half of the camel is often about 127 feet in length; the breadth at one end is 22, and at the other 13. The hold is divided into ſeveral compartments, that the machine may be kept in equilibrio while the water is flowing into it. An Eaſt-India ſhip that draws 15 feet of water can, by the help of the camel, be made to draw only 11; and the heavieſt ſhips of war, of 90 or 100 guns, can be ſo lightened as to paſs, without obſtruction, all the ſand-banks of the Zuydee-Zee.

Leupold, in chap. 6. of his *Theatrum Machinarum*, publiſhed in 1725, at Leipſick, deſcribes this machine under the head *Beſchreibung derſe genannten Camele zu Amſterdam, womit die befrachten Schiffe über dem Pampus gebracht werden,* and ſays it was invented by Cornelius Meyer, a Dutch engineer. But the Dutch writers almoſt unanimouſly aſcribe this invention to a citizen of Amſterdam, called Meuves Meindertſzoon Bakker.

As ſhips built in the Neiva cannot be conveyed into harbour, on account of the ſand-banks formed by the current of that river, camels are employed alſo by the Ruſſians, to carry ſhips over theſe ſhoals: and they have them of various ſizes. Bernoulli ſaw one, each half of which was 217 feet long, and 36 broad. Camels are uſed likewiſe at Venice. An engraving of the camel may be ſeen in *L'Art de batir les Vaiſſeaux*, Amſterdam, 1719, 4to. vol. ii. pa. 93.

CANALS, *motion of water in.* See STREAM.

CAPSTAN, a large maſſy column, ſhaped like a truncated cone, placed perpendicularly on the deck of a ſhip, and turned by levers or bars, which paſs through holes pierced in its upper extremity; ſerving, by means of a cable which winds round the barrel, to draw up burdens faſtened to the end of the cable. The power of this machine in its ſimpleſt ſtate is manifeſtly reducible to that of the axis in peritrochio. There is frequently attached to it a tackle of pulleys, but the ingenious contrivance deſcribed in art. 4 of the introductory part of this volume is far preferable.

CELLAR CRANE, a machine repreſented in fig. 6. pl. VI.; and is very uſeful to wine-merchants, brewers, &c. in drawing up and letting down caſks full of wine, beer, &c. It ſaves the trouble and inconvenience of horſes, and in many places can be uſed where horſes could not. AA are two wooden props, about 6 feet in height, and jointed together like a ruler at B. They are connected to each other by an iron round bar C, and wooden bar at the bottom D. The iron prongs EE faſten the uprights ſteadily to the edge of the cellar; F is the axis round which two ropes are coiled, the ends of which are faſtened to the two clamps GG. On the axis F is fixed the iron wheel H, of 3 feet in diameter: in the teeth of this works the pinion I, of about 6 or 7 inches in diameter, and is turned by the handle at K.

It is evident, by a bare inſpection of the figure, that when the two ropes are ſlipt over the ends upon the barrel, either at the top or bottom of the cellar, by turning of the winch K towards or from you, the barrel can be ſafely and expeditiouſly taken out or lowered down. When the crane is done with it ſhuts up, by unſcrewing the nut at B, taking the wheel and axis away out of the loops at L, and folding the ſides at A together, like a jointed rule; it may then be taken away in the cart or dray, or taken in the men's hands.

CENTRIFUGAL PUMP, a very curious machine, invented by Mr. Erſkine, for raiſing water by means of a centrifugal force combined with the preſſure of the atmoſphere. It conſiſts of a large tube of copper, &c. in the form of a croſs, which is placed perpendicularly in the water, and reſts at the bottom on a pivot. At the upper part of the tube is an horizontal cog-wheel, which touches the cogs of another in a vertical poſition; ſo that by the help of a double winch the whole machine is moved round with very great velocity. Near the bottom of the perpendicular part of the tube is a valve opening upwards; and near the two extremities, but on the contrary ſide of the arms or croſs part of the tube, are two other valves opening outwards. Theſe two valves are, by the aſſiſtance of ſprings, kept ſhut till the machine is put in motion, when the centrifugal velocity of the water forces them open, and diſcharges itſelf into a ciſtern or reſervoir placed there for that purpoſe. On the upper part of the arms are two holes, which are cloſed by pieces ſcrewed into the metal of the tube. Before the machine can work thoſe holes muſt be opened, and water poured in through them, till the whole tube be full; by this means all the air will be forced out of the machine, and the water ſupported in the tube by means of the valve at the bottom. The tube being thus filled with water, and the holes cloſed by the ſcrew-caps, it is turned round by means of the winch, when the water in the arms of the tube acquires a centrifugal force, opens the valves near the extremities of the arms, and flies out with a velocity nearly equal to that of the extremities of the ſaid arms. The theory of this pump may be ſeen in arts. 537, 538, of our firſt volume.

CHIMNEY CLEANSING MACHINES have been lately invented, in order, as far as poſſible, to diminiſh the number of infant victims of a filthy and diſguſting operation, performed under the inſpection of unfeeling maſters. Thoſe who have long viewed the wretchedneſs to which many of the children are expoſed who are ſtill employed in climbing chimneys, will be happy to hear of any contrivances which have a tendency to leſſen their ſufferings: we therefore mention here two machines which have been deviſed for the purpoſe of ſweeping chimneys; either of which may, we doubt not, be made uſe of with conſiderable ſucceſs.

The firſt is that invented by Mr. George Smart, of Ordnance-wharf, Weſtminſter-bridge. Its principal parts are the bruſh, the rods for raiſing the bruſh, and the cord for connecting the whole together. The bruſh conſiſts of four fan-ſhaped or wing-like portions, which are hung upon hinges, in order that in aſcending the chimney the bruſh may take up as little ſpace as poſſible, and in deſcending may ſpread out and ſweep the ſides of the flue: this bruſh is prevented from falling down into its contracted form by a contrivance exactly like that which is made uſe for umbrellas. The ſubſtance made uſe of in general for the bruſh is what is called *whiſk*. The rods are hollow tubes, with a metal ſocket at the lower end; ſome of the ſockets have screws in them, for the purpoſe of confining the cord, and preventing the rods from ſeparating. The upper ends of the rods are now made without ferrules, and are rather tapered, which allows of a small motion within the ſockets. Each rod is about 2½ feet long. The cord runs from the top of the bruſh through all the rods, and when drawn tight keeps the whole of the machine together.

Method of uſing the machine. Having firſt aſcertained, by looking up the chimney, what courſe the flue immediately takes, the cloth is then to be fixed before the fire-place, with the horizontal bar, and the ſides to be cloſed with two upright bars. The next part of the operation is to introduce, through the opening in the cloth, the bruſh in its contracted form: this opening is then to be buttoned or tied up, to prevent the ſoot coming into the apartments; then one of the rods is to be paſſed up the cord into the ſocket, on the lower end of the rod which ſupports the bruſh; the other rods are in like manner, one by one in ſucceſſion, to be brought up, until the bruſh is raiſed ſomewhat above the top of the chimney, obſerving to keep the cord conſtantly tight; and when thoſe rods which have a ſcrew in the ſocket are brought up they are to be placed on the purchaſe, when the cord is to be put round the pulley and drawn very tight, and ſcrewed down, by which all the rods above will be firmly connected together, and the whole may be conſidered one long flexible rod.

When the operator thinks that the bruſh is near the top of the chimney he ſhould move it up and down, as he will then find the bruſh, if out, stop, in returning, on the top of the pot or chimney.

When it is known to be out the machine is to be pulled down: in doing which the edges of the bruſh, ſtriking againſt the top of the chimney, will cauſe it to expand; and there being a ſpring to prevent its contracting again, it will ſweep the ſoot down before it: the whiſk being long and elaſtic, makes the bruſh capable of filling flues of different diameters. In drawing down the machine the perſon ſhould graſp with his left hand the rod immediately above that which he is ſeparating with his right hand, otherwiſe he may chance to have thoſe above looſen and ſlide down the cord, which will render the operation unpleaſant and difficult: the rods, as they are brought down, are to be laid carefully one by one in as ſmall a compaſs as they conveniently can be, that they may not dirt the apartments: with a little attention they may be placed like a bundle of ſticks, ſide by ſide, in very little compaſs. When the bruſh is quite down it is to be ſhaken within-ſide the cloth, then the ſpring muſt be puſhed in, and the bruſh which was expanded will flap down into the ſtate it went up.

If, as ſometimes happens, there is any difficulty found in drawing the bruſh into the upper part of the chimney, the rods muſt be thruſt up again ſomewhat higher, in order to alter the direction, then carefully drawn down. It will be proper to let the cloth remain a ſhort time up (where great cleanlineſs is required), in order to let the finer particles of ſoot ſubſide within it.

For extinguiſhing a chimney on fire, a coarſe cloth is to be tied over the bruſh and dipped into water, then paſſed up as above directed.

It is now nearly three years ſince this machine was invented, and its uſe has been attended with very conſiderable succeſs; for it appears that there is ſcarcely one chimney in a hundred in the vicinity of the metropolis but what may be properly ſwept by it. The following perſons have undertaken to ſweep chimneys with Mr. Smart's machines, at the uſual prices:—*Thomas Badger*, chimney-ſweeper, No. 2, Whalebone-court, oppoſite Token-houſe-yard, Great Bell-alley, Coleman-ſtreet.—*John Bedford*, chimney-ſweeper, 56, Swallow-street, Piccadilly.—*Thomas Murleſs*, chimney-ſweeper, Bell-yard, near the Bridge, Hackney.—*Richard Page*, chimney-ſweeper, 23, Colonnade, near Guildford-street, Foundling-hoſpital.—*George Smart*, 15, Great Bell-alley, Coleman-street; and at his timber-yard, Pratt's-place, Camden-town; and at Ordnance-wharf, Weſtminſter-bridge.—*Thomas Taylor*, 9, Well's-ſtreet, Oxford-road.—*George Turner* and *James Laver*, Walthamſtow.—*Thomas Wood*, 36, Poland-ſtreet, Oxford-road.

Another machine for the ſame benevolent purpoſe has been invented by Mr. J. C. Hornblower, engineer, Eaſt-place, City-road. The apparatus is ſimply this: a veſſel into which air is condenſed communicates with a tube charged with ſmall gravel, which being blown up the chimney brings down the ſoot.

The body of the machine is made of copper, of about 3 pound to the ſquare foot, and its capacity is about three cylindrical feet. In the middle of the cover, which is ſoldered on, is a ſyringe or condenſer, having its handle above the cover.

On one ſide of the cover is inſerted a crooked pipe, having a valve opening inward in its inner or lower end, the ſtem of which comes up through the pipe, and terminates with a button. The pipe is continued by a flexible leather one, to which is united a tube of tin plate. This latter tube has a croſs bar of tin plate, fixed edgewiſe in the bottom or breach of the tube which detaches from the leather pipe, ſomewhat like a piſtol barrel, leaving a piece of tube about ſix inches remaining to the leather pipe, into the bottom of which this caſe bar is fixed, and ſerves to receive a charge of ſmall gravel, having a piece of paper firſt laid on the croſs-bar; the other part of the tube is then to be replaced, and the air-veſſel ſuppoſed to be full, the valve is preſſed down by a little lever accompanying the machine, and its contents are diſcharged into the ſhaft of the chimney; and if there is any ſuch quantity of ſoot as really needs ſweeping away, it will come down.

The veſſel contains nearly three cylindrical feet, and we can crowd three atmoſpheres of air into it, in which caſe there will be 42 lbs. per inch ſquare, at round numbers, preſſing againſt the charge in the tube, or rather againſt the valve, the tube being 2_4 inch diameter, which amounts to 168 lbs. for the whole area. This air will all be diſcharged in one ſecond, the mean velocity of which may be fairly reckoned at 50 feet, in that time having impetus in itſelf ſufficient to carry away any ſoot of conſequence in a chimney of 100 feet high; but when we take into the account the charge of gravel, being alternately incident and reflected on all ſides of the chimney, we need not fear to affirm that it is perfectly applicable to its intention.

To render it as univerſal as poſſible there muſt be another tube, to be occaſionally uſed, when the ſide of the chimney near the fire place is gathered over, in order to bring the throat of the flue over the fire: or it ſhould be in ſeveral pieces, to conform to the height of this gathering, and in this caſe the charge muſt be at the upper fiſſure, and the pipe ſtayed as perpendicularly as can be conveniently done; for which purpoſe there is a piece made to fix on the pipe, having two ſtems, which, if put in the bearing ſide of the pipe, will keep it upright and in the crater of the flue. The machine thus conſtructed is to be laid on a little truck, and tranſported from houſe to houſe, with a gallon of gravel to begin with; becauſe, until it has obtained the good opinion of the public, it would not be neceſſary to attempt ſuch regulations as would afterwards be deemed requiſite to facilitate the operation.

The inventor of this condenſing machine, in a letter on the ſubject in Nicholſon's Journal, N. S. No. 28, has made ſome ingenious obſervations on the peculiarity of its conſtruction, and what he thinks its advantages, compared with the machine previouſly deſcribed in this article.—“ One circumſtance,” ſays he, “ preſents itſelf, by which the air machine muſt have a decided preference over the bruſhes; which is this, you muſt know the height of the chimney, and adapt the length of the rods to that height, or elſe you will not know when you are in the flue or out of it. Whereas, my machine knows no neceſſity for ſuch a punctilio; all that is neceſſary being only to give ſo many ſhocks of the condenſer to a chimney of two ſtories, and ſo many to one of three, and ſo on. And again, theſe bruſhes in the very outſet of trial made with them are ſubject to accidents, and will moſt aſſuredly wear out very faſt. What muſt become of thoſe whalebone rods when the ſewing is rubbed through in paſſing up and down againſt the projections of unceremonious bricks and mortar? What repairs will they not be ſubject to in the courſe of one day's action? Whereas the air machine will ſweep a hundred chimneys, and be repaired for two-pence; it wanting only a little oil in the condenſer.”

Our readers will decide for themſelves, from the preceding deſcriptions, which contrivance deſerves the preference. We are gratified in having an opportunity of ſpeaking of both, deeming that a laudable endeavour which is intended to recommend to the public the uſe of one or other of two machines well calculated for the purpoſe of performing a moſt diſagreeable and ſometimes dangerous operation; thereby relieving a degraded claſs of our ſpecies from very inhuman treatment, and reſtoring them to their rank in civil ſociety.

CHUCK, UNIVERSAL. See TURNING

CHURN, a well-known veſſel in which butter, by long and violent agitation, is ſeparated from the ſerous part of the milk.

The inferiority of the churns in common uſe has induced ſeveral ingenious mechanics to exert their ſkill in contriving others that would render the proceſs of making butter leſs tedious and expenſive. Of theſe, one of the moſt valuable is Mr. *William Bowler*'s improved churn, with which the Society for the Encouragement of Arts, &c. were ſo well ſatisfied as to preſent the inventor with thirty guineas. As it renders the operation of churning far leſs fatiguing; and has, beſides, ſome peculiar advantages, we ſhall ſubjoin a deſcription.

This churn is of the barrel kind, being a cylinder 18 inches in diameter, and 9 wide; the ſides are of wood, and the rim a tin plate, which has two openings, one $8\frac{1}{2}$ inches in length, and 4 in width, through which the cream is poured into the churn, and the hand introduced for cleaning it; the other a ſhort pipe, one inch in diameter, by which the butter-milk runs out of the churn when the operation is finiſhed. The firſt of theſe openings has a wooden cover, faſtened down by two ſcrews; and the other a cork fitted to it, while the butter is churning. There is further, near the larger opening, a ſmall vent-hole with a peg, to admit the paſſage of any air that may be diſcharged from the cream at the beginning of the operation. An axle alſo paſſes through the churn, terminating in two gudgeons, on which it hangs; its lower part being immerſed in a trough, in order to hold occaſionally either hot or cold water, according to the ſeaſon of the year. On the inſide of the rim are four projecting pieces of wood, with holes, ſerving to agitate the cream by the motion of the churn. This movement is cauſed by a pendulum 3 feet 6 inches long, that has an iron bob weighing 10 lbs. and at its upper end a turning pulley 10 inches in diameter, from which a rope goes twice round another pulley about 3 inches in diameter fixed on the axis of the churn, which it cauſes to make a partial revolution by each vibration of the pendulum.

There are likewiſe ſliding covers to the machinery, and another to the water trough; in order, when hot water is uſed, to ſecure the ſteam, and keep the cream in a proper degree of warmth. The motion of the pendulum is given, and continued, by means of a wooden rod about 3 feet 9 inches in length, which turns on a pin 3 inches above the bob of the pendulum. If there be a tranſverſe handle at the upper end of this wooden rod a boy may give motion to the churn with great facility, even while ſitting; the action being then much like that of rowing, one of the moſt advantageous methods of applying human force.

AA, fig. 8, pl. XII. is the body. B, an opening by which the cream is put in. C, the cover of the large opening: the ſmall hole on the oppoſite ſide of the churn cannot be ſhewn in this view. D, the gudgeon on which the body of the churn hangs. E, the upper or larger pully. F, the ſmaller pulley fixed on the axis or gudgeon of the churn. GG, the rod of the pendulum hanging from the upper pulley E. H, the bob of the pendulum. II, the handle, moveable on a pin at *a*, by which the pendulum is moved to and fro, making a traverſe in form of the dotted line KK. L, the trough for the hot or cold water. M, a projecting piece of wood, with a ſhoulder, by which the handle I is ſupported when the churn is not at work.

CLOCK, a machine now conſtructed in ſuch a manner, and ſo regulated by the uniform motion of a pendulum, as to meaſure time, and all its ſubdiviſions, with great exactneſs. Before the invention of the pendulum a balance, not unlike the fly of a kitchen-jack, was uſed inſtead of it. Clocks were at firſt called nocturnal dials, to diſtinguiſh them from ſun-dials, which ſhewed the hour by the ſhadow of the ſun.

The invention of clocks with wheels is aſcribed to Pacificus, archdeacon of Verona, in the 9th century, on the credit of an epitaph quoted by Ughelli, and borrowed by him from Panvinius. Others attribute the invention to Boethius, about the year 510.

Mr. Derham, however, makes clock-work of a much older date; ranking Archimedes's ſphere, mentioned by Claudian, and that of Poſidonius, mentioned by Cicero, among machines of this kind: not that either their form or uſe was the ſame with thoſe of ours, but that they had their motion from ſome hidden weights or ſprings, with wheels or pulleys, or ſome ſuch clockwork principle.

In the *Diſquiſitiones Monaſticæ* of Benedictus Haeften, publiſhed in the year 1644, he ſays, that clocks were invented by Silveſter the 4th, a monk of his order, about the year 998, as Dithmarus and Bozius have ſhewn; for before that time they had nothing but ſun-dials and clepſydræ to ſhew the hour.—Conrade Geſner, in his Epitome, page 604, ſays, that Richard Wallingford, an Engliſh abbot of St. Albans, who flouriſhed in the year 1326, made a wonderful clock by a moſt excellent art, the like of which could not be produced by all Europe.—Moreri, under the word *Horologe* du Palais, ſays, that Charles the Fifth, called the wiſe king of France, ordered at Paris the firſt large clock to be made by Henry de Vic, whom he ſent for from Germany, and ſet it upon the tower of his palace in the year 1372.—John Froiſſart, in his *Hiſtoire & Chronique*, vol. 2, chap. 28, ſays, the duke of Bourgogne had a clock which ſounded the hour, taken away from the city of Courtray in the year 1382: and the ſame thing is ſaid by William Paradin in his *Annals de Bourgogne*.

Clock-makers were firſt introduced into England in 1368, when Edward the Third granted a licence for three artiſts to come over from Delft, in Holland, and practiſe their occupation in this country.

The water-clocks or clepſydræ, and ſun-dials, have both a much better claim to antiquity. The French annals mention one of the former kind, ſent by Aaron, king of Perſia, to Charlemagne, about the year 807, which it would ſeem bore ſome reſemblance to the modern clocks: it was of braſs, and ſhewed the hours by 12 little balls of the ſame metal, which at the end of each hour fell upon a bell, and made a ſound. There were alſo figures of 12 cavaliers, which at the end of each hour came out through certain apertures or windows in the ſide of the clock, and ſhut them again, &c.

The invention of pendulum clocks is owing to the happy induſtry of the laſt age; and the honour of that diſcovery is diſputed between Galileo and Huygens. The latter, who wrote an excellent volume on the ſubject, declares it was firſt put in practice in the year 1657, and the deſcription of it printed in 1658. Becher, *De Nova Temporis dimetiendi Theoria*, *anno* 1680, contends for Galileo; and relates, though at ſecond-hand, the whole hiſtory of the invention; adding, that one Treſler, clock-maker to the father of the then grand-duke of Tuſcany, made the firſt pendulum clock at Florence under the direction of Galileo Galilei, a pattern of which was brought to Holland. And the Academy del Cimento ſays expreſsly, that the application of the pendulum to the movement of a clock was firſt propoſed by Galileo, and put in practice by his ſon Vincenzo Galilei in 1649. But whoever may have been the inventor, it is certain that the invention never flouriſhed till it came into the hands of Huygens, who inſiſts on it that, if ever Galileo thought of ſuch a thing, he never brought it to any degree of perfection. The firſt pendulum clock made in England was in the year 1662, by one Fromantil, a Dutchman.

After this brief ſketch of the hiſtory of clocks, which may be intereſting to ſome of our readers, we ſhall give a deſcription of a modern clock according to the moſt approved conſtruction. The firſt figure of plate VIII. is a profile of ſuch a clock; P is a weight which is ſuſpended by a cord that winds about the cylinder or barrel C, which is fixed upon the axis *a*, *a*; the pivots *b*, *b*, go into holes made in the plates TS, TS, in which they turn freely. Theſe plates are made of braſs or iron, and are connected by means of *four* pillars, Z, Z; the whole together being called the *frame*. The weight P, if not reſtrained, would neceſſarily turn the barrel C, with an uniformly accelerating motion, in the ſame manner as if the weight were falling freely. But the barrel is furniſhed with a ratchet-wheel, K, K, the right ſide of whoſe teeth ſtrikes againſt the click, which is fixed with a ſcrew to the wheel DD, as repreſented in fig. 2; ſo that the action of the weight is communicated to the wheel DD, the teeth of which act upon the teeth of the ſmall wheel *d*, which turns upon the pivots *c*, *c*. The communication or action of one wheel with another is called the *pitching*; a ſmall wheel like *d* is called a *pinion*, and its teeth are called *leaves* of the pinion. Several things are requiſite to form a good pitching, the advantages of which are obvious in all machinery where teeth and pinions are employed. The teeth and pinion-leaves ſhould be of a proper ſhape, and perfectly equal among themſelves: the ſize alſo of the pinion ſhould be of a juſt proportion to the wheel acting into it.

The wheel EE is fixed upon the axis of the pinion *d*, and the motion communicated to the wheel DD by the weight is tranſmitted to the pinion *d*, conſequently to the wheel EE, as likewiſe to the pinion *e* and wheel FF, which moves the pinion *f*, upon the axis of which the crown or balance wheel GH is fixed. The pivots of the pinion *f* play in holes of the plates LM, which are fixed horizontally to the plates TS. In a word, the motion begun by the weight is tranſmitted from the wheel GH to the palettes IK, and by means of the fork UX rivetted on the palettes, communicates motion to the pendulum AB, which is ſuſpended upon the hook A. The pendulum AB deſcribes, round the point A, an arc of a circle alternately going and returning. If, then, the pendulum be once put in motion by a puſh of the hand, the weight of the pendulum at B will make it return upon itſelf, and it will continue to go alternately backward and forward till the reſiſtance of the air upon the pendulum, and the friction at the point of ſuſpenſion at A, deſtroys the original impreſſed force. But as at every vibration of the pendulum the teeth of the balance-wheel GH act ſo upon the palettes IK (the pivots upon the axis of theſe palettes play in two holes of the potence *s t*), that after one tooth H has communicated motion to the palette K, that tooth eſcapes; then the oppoſite tooth G acts upon the palette I, and eſcapes in the ſame manner; and thus each tooth of the wheel eſcapes the palettes IK, after having communicated their motion to the palettes in ſuch a manner that the pendulum, inſtead of being ſtopped, continues to move. The wheel EE revolves in an hour; the pivot *c* of this wheel paſſes through the plate, and is continued to *r*; upon the pivot is a wheel NN, with a long ſocket faſtened in the centre; upon the extremity of this ſocket *r*, the minute-hand is fixed The wheel NN acts upon the wheel O; the pinion of which *p* acts upon the wheel *gg*, fixed upon a ſocket which turns along with the wheel N. This wheel *gg* makes its revolution in 12 hours, upon the ſocket of which the hour-hand is fixed.

From the above deſcription it is eaſy to ſee, 1. That the weight P turns all the wheels, and at the ſame time continues the motion of the pendulum. 2. That the quickneſs of the motion of the wheels is determined by that of the pendulum. 3. That the wheels point out the parts of time divided by the uniform motion of the pendulum.

When the cord upon which the weight is ſuſpended is entirely run down from off the barrel, it is wound up again by means of a key, which goes on at the ſquare end of the arbor at Q, by turning it in a contrary direction from that in which the weight deſcends. For this purpoſe the inclined ſide of the teeth of the wheel K (fig. 2.) removes the click C, ſo that the ratchet-wheel R turns while the wheel D is at reſt; but as ſoon as the cord is wound up, the click falls in between the teeth of the wheel D, and the right ſide of the teeth again act upon the end of the click, which obliges the wheel D to turn along with the barrel; and the ſpring A keeps the click between the teeth of the ratchet wheel R.

We ſhall now explain how time is meaſured by the motion of the pendulum; and how the wheel E, upon the axis of which the minute-hand is fixed, makes but one preciſe revolution in an hour. The vibrations of a pendulum are performed in a ſhorter or longer time in proportion to the length of the pendulum itſelf. A pendulum of $39\frac{1}{8}$ inches in length makes 3600 vibrations in an hour: *i. e.* each vibration is performed in a ſecond of time, and for that reaſon it is called a *ſecond pendulum*. But a pendulum of $9\frac{25}{32}$ inches makes 7200 vibrations in an hour, or two vibrations in a ſecond of time, and is called *a half-ſecond pendulum*. Hence, in conſtructing a wheel whoſe revolution muſt be performed in a given time, the time of the vibrations of the pendulum which regulates its motion muſt be conſidered. Suppoſing, then, that the pendulum AB makes 7200 vibrations in an hour, let us conſider how the wheel E ſhall take up an hour in making one revolution. This entirely depends on the number of teeth in the wheels and pinions. If the balance-wheel conſiſts of 30 teeth, it will turn once in the time that the pendulum makes 60 vibrations: for at every turn of the wheel the ſame tooth acts once on the palette I, and once on the palette K, which occaſions two ſeparate vibrations in the pendulum; and the wheel having 30 teeth it occaſions twice 30, or 60 vibrations. Conſequently this wheel muſt perform 120 revolutions in an hour; becauſe 60 vibrations, which it occaſions at every revolution, are contained 120 times in 7200, the number of vibrations performed by the pendulum in an hour. Now, in order to determine the number of teeth for the wheels E F, and their pinions *e f*, it muſt be remarked that one revolution of the wheel E muſt turn the pinion *e* as many times as the number of teeth in the pinion is contained in the number of teeth in the wheel. Thus, if the wheel E contains 72 teeth, and the pinion *e* 6, the pinion will make 12 revolutions in the time that the wheel makes 1; for each tooth of the wheel drives forward a tooth of the pinion, and when the 6 teeth of the pinion are moved, a complete revolution is performed; but the wheel E has by that time only advanced 6 teeth, and has ſtill 66 to advance before its revolution be completed, which will occaſion 11 more revolutions of the pinion. For the ſame reaſon the wheel F having 60 teeth, and the pinion *f* 6, the pinion will make 10 revolutions while the wheel performs 1. Now the wheel F being turned by the pinion *e* makes 12 revolutions for one of the wheel E; and the pinion *f* makes 10 revolutions for one of the wheel F; conſequently the pinion *f* performs 10 times 12, or 120, revolutions in the time the wheel E performs one. But the wheel G, which is turned by the pinion *f*, occaſions 60 vibrations in the pendulum each time it turns round; conſequently the wheel G occaſions 60 times 120, or 7200, vibrations of the pendulum while the wheel E performs one revolution; but 7200, is the number of vibrations made by the pendulum in an hour, and conſequently the wheel E performs but one revolution in an hour; and ſo of the reſt.

From this reaſoning it is eaſy to diſcover how a clock may be made to go for any length of time without being wound up. 1. By increaſing the number of the teeth in the wheels. 2. By diminiſhing the number of teeth in the pinions. 3. By increaſing the length of the cord that ſuſpends the weight. 4. By increaſing the length of the pendulum. And, 5. By adding to the number of wheels and pinions. But in proportion as the time is augmented, if the weight continues the ſame, the force which it communicates to the laſt wheel GH will be diminiſhed.

It only remains to take notice of the number of teeth in the wheels which turn the hour and minute-hands. The wheel E performs one revolution in an hour; the wheel N N, which is turned by the axis of the wheel E, muſt likewiſe make only one revolution in the ſame time; and the minute-hand is fixed to the ſocket of this wheel. The wheel N has 30 teeth, and acts upon the wheel O, which has likewiſe 30 teeth, and the ſame diameter; conſequently the wheel O takes one hour to a revolution: now the wheel O carries the pinion *p*, which has 6 teeth, and which acts upon the wheel *q q* of 72 teeth; conſequently the pinion *p* makes 12 revolutions while the wheel *q q* makes one, and of courſe the wheel *q q* takes 12 hours to one revolution; and upon the ſocket of this wheel the hour-hand is fixed. Much that has been ſaid here concerning revolutions of wheels, &c. is equally applicable to watches as to clocks.

But it is time to ſpeak of the ſtriking part; in which, indeed, as well as the other part of a clock, there is room for great variety and choice in the conſtruction. The wheels uſually compoſing this part are, the great or firſt wheel, which is moved by the weight or ſpring at the barrel, in ſixteen or thirty-hour clocks; this has uſually pins, and is called the *pin-wheel*; in eight-day pieces the ſecond wheel is commonly the pin-wheel, or ſtriking-wheel, which is moved by the former.

Next to the ſtriking-wheel is the detent-wheel, or hoop-wheel, having a hoop almoſt round it, wherein is a vacancy at which the clock locks. The next is the third or fourth wheel, according to its diſtance from the reſt, called the *warning-wheel.* The laſt is the flying pinion, with a fly or fan, to gather air, and ſo bridle the rapidity of the clock's motion. To theſe muſt be added the pinion of report; which drives round the locking-wheel, called alſo the *count-wheel;* ordinarily with eleven notches in it, unequally diſtant, to make the clock ſtrike the hours. Beſides the wheels, to the clock part belongs the raſh or ratch; a kind of wheel with twelve large fangs, running concentrical to the dial-wheel, and ſerving to lift up the detents every hour and make the clock ſtrike: the detents or ſtops, which being lifted up and let fall, lock and unlock the clock in ſtriking; the hammer, which ſtrikes the bell; the hammer-tails, by which the ſtriking pins draw back the hammers; latches, whereby the work is lifted up and unlocked; and lifting-pieces which lift up and unlock the detents.

In the year 1803 the Society for the Encouragement of Arts, &c. preſented to Mr. John Prior of Neſsfield, Yorkſhire, a reward of 30 guineas, on account of his contrivance for the *ſtriking* part of an eight-day clock. As this invention is likely to be uſeful, we ſhall deſcribe it here. It conſiſts of a wheel and fly, with ſix turns of a ſpiral line, cut upon the wheel for the purpoſe of counting the hours. The pins below this ſpiral elevate the hammer, and thoſe above are for the uſe of the detent. This ſingle wheel ſerves the purpoſe of count-wheel, pin-wheel, detent-wheel, and the fly-wheel, and has ſix revolutions in ſtriking the 12 hours. If we ſuppoſe a train of wheels and pinions uſed in other ſtriking parts to be made without error, and that the wheels and pinions would turn each other without ſhake or play: then, allowing the above ſuppoſition to be true (though every mechanic knows it is not), Mr. Prior's ſtriking part would be found ſix times ſuperior to others, in ſtriking the hours 1, 2, 5, 7, 10, 11; twelve times ſuperior in ſtriking 4, 6, 8; and eighteen times, in ſtriking 3, 9, and 12. In ſtriking 2, the inventor purpoſely made an imperfection equal to the ſpace of three teeth of the wheel; and, in ſtriking 3, an imperfection of nine or ten teeth; and yet both theſe hours are ſtruck perfectly correct. The flies in clocks turn round, at a mean, about ſixty times for every knock of the hammer, but this turns round only three times for the ſame purpoſe; and ſuppoſe the pivots were of equal diameters, the influence of oil on them would be as the number of revolutions in each. It would be better for clocks if they gave no warning at all, but the ſnail-piece to raiſe a weight ſomewhat ſimilar to the model Mr. P ſent for the inſpection of that reſpectable Society.

Reference to Mr. PRIOR'*s Striking Part of his Clock.*

Plate X. fig. 1. A, the large wheel, on the face of which are ſunk or cut the ſix turns of a ſpiral.

B, the ſingle worm ſcrew, which acts on the above wheel, and moves the fly C.

D, the ſpiral work of the wheel A. The black ſpots ſhew the grooves into which the detents drop on ſtriking the hour.

E, the groove into which the locking-piece F drops when it ſtrikes one, and from which place it proceeds to the outward parts of the ſpiral in the progreſſive hours, being thrown out by a lifting piece H at each hour: the upper detent G being pumped off with the locking piece F, from the pins in the wheel A.

In ſtriking the hour of *twelve*, the locking-piece, having arrived at the outer ſpiral at H, riſes up an inclined plane, and drops by its own weight to the inner circle, in which the hour *one* is to be ſtruck, and proceeds on in a progreſſive motion through the different hours till it comes again to *twelve*.

I, the hammer-work made in the common way, which is worked by thirteen pins on the face of the ſpiral.

Fig. 2.—K, the thirteen pins on the face of the ſpiral, which work the hammer-work.

L, the outer pins, which lock the detent.

M, the pump-ſpring to the detent.

For other information reſpecting clockwork, ſee the articles BALANCE, PENDULUM, and SCAPEMENT, in this volume.

Some very ſimple contrivances for clocks, by Mr. Ferguſon, and Dr. Franklin, may be ſeen in *Ferguſon's Select Exerciſes*.

In the fourth century an artiſt named James Dondi conſtructed a clock for the city of Padua, which was long conſidered as the wonder of that period. Beſides indicating the hours, it repreſented the motion of the ſun, moon, and planets, as well as pointed out the different feſtivals of the year. On this account Dondi obtained the ſurname of Horologio, which became that of his poſterity. A little time after, William Zelander conſtructed for the ſame city a clock ſtill more complex; which was repaired in the ſixteenth century by Janellus Turrianus, the mechaniſt of Charles V.

But the clocks of the cathedrals of Straſburgh and of Lyons, are much more celebrated. That of Straſburgh was the work of Conrad Daſypodius, a mathematician of that city, who finiſhed it about 1573. The face of the baſement of this clock exhibits three dial-plates; one of which is round, and conſiſts of ſeveral concentric circles; the two interior ones of which perform their revolutions in a year, and ſerve to mark the days of the year, the feſtivals and other circumſtances of the calendar. The two lateral dial-plates are ſquare, and ſerve to indicate the eclipſes both of the ſun and the moon. Above the middle dial-plate, and in the attic ſpace of the baſement, the days of the week are repreſented by different divinities, ſuppoſed to preſide over the planets from which their common appellations are derived. The divinity of the current day appears in a car rolling over the clouds, and at midnight retires to give place to the ſucceeding one. Before the baſement is ſeen a globe, borne on the wings of a pelican, around which the ſun and moon revolved; and which in that manner repreſented the motion of theſe planets: but this part of the machine, as well as ſeveral others, has been deranged for a long time. The ornamental turret, above this baſement, exhibits chiefly a large dial in the form of an aſtrolabe; which ſhews the annual motion of the ſun and moon through the ecliptic, the hours of the day, &c. The phaſes of the moon are ſeen alſo marked out on a particular dial-plate above. This work is remarkable alſo for a conſiderable aſſemblage of bells and figures, which perform different motions. Above the dial-plate laſt mentioned, for example, the four ages of man are repreſented by ſymbolical figures: one paſſes every quarter of an hour, and marks the quarter by ſtriking on ſmall bells; theſe figures are followed by Death, who is expelled by Jeſus Chriſt riſen from the grave; who, however, permits it to ſound the hour, in order to warn man that time is on the wing. Two ſmall angels perform movements alſo; one ſtriking a bell with a ſceptre, while the other turns an hour-glaſs at the expiration of an hour. In the laſt place, this work was decorated with various animals, which emitted ſounds ſimilar to their natural voices; but none of them now remains, except the cock, which crows immediately before the hour ſtrikes, firſt ſtretching out its neck and clapping its wings. Indeed it is to be regretted that a great part of this machine is now entirely deranged.

The clock of the cathedral of Lyons is of leſs ſize than that of Straſburgh, but is not inferior to it in the variety of its movements; it has the advantage alſo of being in a good condition. It is the work of Lippius de Baſle, and was exceedingly well repaired in the laſt century by an ingenious clock-maker of Lyons named Nouriſſon. Like that of Straſburgh, it exhibits on different dial-plates the annual and diurnal progreſs of the ſun and moon, the days of the year, their length, and the whole calendar, civil as well as eccleſiaſtic. The days of the week are indicated by ſymbols more analogous to the place where the clock is erected; the hours are announced by the crowing of a cock, three times repeated after it has clapped its wings, and made various other movements. When the cock has done crowing, angels appear; who, by ſtriking various bells, perform the air of a hymn; the annunciation of the Virgin is repreſented alſo by moving figures, and by the deſcent of a dove from the clouds; and after this mechanical exhibition the hour ſtrikes. On one of the ſides of the clock is ſeen an oval dial-plate, where the hours and minutes are indicated by means of an index, which lengthens or contracts itſelf, according to the length of the ſemidiameter of the ellipſis over which it moves.

A very curious clock, the work of Martinot, a celebrated clock-maker of the ſeventeenth century, was formerly to be ſeen in the royal apartments at Verſailles. Before it ſtruck the hour, two cocks on the corners of a ſmall edifice crowed alternately, clapping their wings: ſoon after two lateral doors of the edifice opened, at which appeared two figures bearing cymbals, beat upon by a kind of guards with clubs. When theſe figures had retired, the centre door was thrown open, and a pedeſtal, ſupporting an equeſtrian ſtatue of Louis XIV. iſſued from it, while a group of clouds ſeparating, gave a paſſage to a figure of Fame, which came and hovered over the ſtatue. An air was then performed by bells: after which the two figures re-entered; the two guards raiſed up their clubs, which they had lowered as if out of reſpect for the preſence of the king, and the hour was then ſtruck.

While, however, we have thought it right to deſcribe theſe ingenious performances of foreign artiſts, we muſt not neglect to mention the equally ingenious workmanſhip of ſome of our own countrymen. We now refer to two clocks made by Engliſh artiſts, as a preſent from the Eaſt-India company to the emperor of China. Theſe two clocks are in the form of chariots, in each of which a lady is placed in a fine attitude, leaning her right hand upon a part of the chariot, under which appears a clock of curious workmanſhip, little larger than a ſhilling, that ſtrikes and repeats, and goes for eight days. Upon the lady's finger ſits a bird, finely modelled, and ſet with diamonds and rubies, with its wings expanded in a flying poſture, and actually flutters for a conſiderable time on touching a diamond button below it: the body of the bird, in which are contained part of the wheels that animate it as it were, is leſs than the 16th part of an inch. The lady holds in her left-hand a golden tube little thicker than a large pin, on the top of which is a ſmall round box, to which is fixed a circular ornament not larger than a ſixpence, ſet with diamonds, which goes round in near three hours in a conſtant regular motion. Over the lady's head is a double umbrella, ſupported by a ſmall fluted pillar not thicker than a quill, and under the larger of which a bell is fixed, at a conſiderable diſtance from the clock, with which it ſeems to have no connection; but from which a communication is ſecretly conveyed to a hammer, that regularly ſtrikes the hour, and repeats the ſame at pleaſure, by touching a diamond button fixed to the clock below. At the feet of the lady is a golden dog.

As the ſubject of clock and watch making is very important, we think the following copious catalogue of the chief writings relating to it, both in theory and practice, may be acceptable and beneficial to many of our readers.

Carmen de aſtronomico horologio argentoratenſi, ſcriptum a M. *Nicodemo Friſchlino* Balingenſi, academiæ Tubingenſis profeſſore. A. D. 1575.

Deſcriptio brevis et ſuccincta horologii rariſſimi æque ac pretioſiſſimi, ab ingenioſiſſimo mechanico *Jo. Davide Lieberkühn* conſtructi. 1576.

Conradi Daſypodii heron mechanicus. Ejuſdem horologii aſtronomici, &c. 1580.

Brevis deſcriptio artificioſi novi et aſtronomici automati horologii, cujus ſimile ante hac non exſtitit; inventi primum ſtudio et induſtria M. *Jacobi Cunonis*. 1581.

Traité de géométrie et d'horologiographie pratique, par *Jean Bullant*. 1602.

Horologium aſtronomicum Upſalienſe, cujus artificioſiſſima ſtructura, analyſis, et uſus, &c. Auctore *Laurent. Fornelio*, 1630.

Jo. Sarazini horographum catholicum ſeu univerſale, quo omnia horologia ſciotherica deſcribuntur. 1630.

Le nouveau ſciatère pour fabriquer d'horloges. 1633.

Athanaſii Kircheri ars magnis lucis et umbræ. 1646.

Johannis Baptiſta Trotta novum horologium nocturnam é ſtellis. 1651.

Chriſtiani Hugenii a Zulichem Conſt. F. horologium. 1658.

[It was in this elegant little piece that Huygens firſt treated of the regulation of time by the pendulum; and on this he entered more at large in his celebrated work, Horologium oſcillatorium.]

A narrative concerning the ſucceſs of pendulum watches at ſea for finding the longitude, by *Major Holmes*. Phil. Trans. No. 1. 1665.

Antonio Tempera l'horologio giuſto utiliſſimo a naviganti. 1668.

Chr. Hugenii Zulechemii Conſt. F. horologium oſcillatorium, ſive de motu pendulorum ad horologia aptato demonſtrationes geometricæ. Pariſiis. 1673.

I. S. Horological dialogues, in three parts; ſhewing the nature, uſe, and right managing of clocks and watches: with an appendix, containing Mr. Oughtred's method for calculating of numbers. 1675.

Very exact portable watches, by Mr. Huygens. Phil. Trans. No. 112. A. D. 1675.

M. Leibnitz on his portable watches. Phil. Trans. No. 113. A. D. 1675.

Compendium horologico-ſciotericum et geometricum. *Chr. Zuicker.* 1675.

Factum de M. l'abbé de *Hautefeuille* touchant les pendules de poche, contre Mr. Huyghens. 1675.

M. Campani de Alimenis horologium ſolo naturæ motu atque ingenio, &c. 1677.

Traité d'horologiographie du père *de la Magdeleine.* 1680.

D. I. I. Becheri, de nova temporis dimetiendi ratione, et accurata horologiorum conſtructione, theoria et experientia, Londini. 1680.

Horologia ſcioterica prælibata ad delineandum ſciotericon declinationis ſolaris quantum indies eſt perceptibilis, per *N. Hanbury.* Lond. 1683.

Horologium horologiorum deſcriptum et explicatum, ab *Joanne Bartholo. Fichelli.* Venetiis. 1685.

Henrici Coetſii Arnhemienſis horologiographia plana, ſeu methodus in ſuperficiebus planis omnia horologiorum genera deſcribenda methodus. Lugd. Batav. 1689.

Horological diſquiſitions. A work very neceſſary for all that would underſtand the true way of rightly managing clocks and watches. By *John Smidt,* C. M. 1694.

The artificial clock-maker, a treatiſe of watch and clock-work, by W. D. [W. Derham.] 1696.

[This uſeful little work has gone through many editions. It was tranſlated into the German language in 1708, and into the French in 1731.]

Remarques ſur la conſtruction des horloges à pendule, par M. *de la Hire,* mem. R. Acad. 1700, pa. 161.

De la figure des fuſées des horloges à reſſort, par M. Varignon, mem. R. Acad. 1702, pa. 122. Mécan.

The invention of making clocks to keep time with the ſun's apparent motion aſſerted by *W. J. Williamſon.* Phil. Trans. No. 363.

Regle artificielle du tems pour aprendre la diviſion naturelle et artificielle du tems, et connoître toutes ſortes d'horloges et de montres, et la maniere de s'en ſervir adroitement, par *H. S. de Londres.* Imprimé à Vienne. 1714.

This curious work, the author *Henry Sully,* went through various editions in different languages.]

Conſtruction d'un horloge qui marque le tems vrai avec le moyen. Par M. *de la Hire.* mem. R. Acad. 1717.

Horologiographie pratique, ou la manière de faire des horloges à poids et les montres, par le religieux Auguſtin *P. B.* à Rouen. 1719.

Deſcription d'une grande et merveilleuſe horloge portative en pendule, la plus admirable et ſurprenante que aye jamais parû au monde: digne de l'admiration des beaux eſprits: étant l'unique au monde de ſon eſpèce; nouvelle parachevée par l'inventeur, qui eſt le Sr. *T. Paſtre*, ci-devant marchand fabriquant en bas de ſoye et laine, à la ville de Nimes en Languedoc. 1721.

Conſtruction nouvelle de trois montres portatives d'un nouveau balancier en forme de croix, qui fait les oſcillations des pendules très-petites, &c. par M. *de Hautefeuille.* 1722.

Deſcription d'une horloge d'une nouvelle invention pour la juſte meſure du tems ſur mer, par *Sully*. 1726.

A contrivance to avoid the irregularities in a clock's motion, occaſioned by the action of heat and cold on the pendulum rod, by Mr. *George Graham*, watchmaker, F. R. S, Phil. Trans. No. 392. A. D. 1726.

Traité général des horloges, par le père Dom *Jacques-Alexandre.* 1734.

Moyens de conſtruire un pendule qui ne peut s'alonger par la chaleur ni ſe racourcir par le froid, par M. Caſſini, mem. R. Acad, 1741.

Traité de l'horlogerie mechanique et pratique, approuvé par l'Académie Royal des Sciences, par M. *Thiout* l'aine. 1741.

[Much alſo on the ſubjects of pendulums, ſcapements, &c. may be ſeen in the account of *machines et inventions approuvées par l'Acad. Roy. des Sciences*. vol. 1 to 5.]

Joh. George Hartmanns Klein-Uhrmachers zu Jena nöthiger Unterricht von Verbeſſerung der Sackuhren, durch den waagerechten Stand, Berechnung, Auſarbeitung, Beurtheilung, Gebrauch, Stellung, Kennzeichen und Probirung derſelben. 1752.

Traité d'horlogerie, par M. *J. A. le Paute.* 1755.

Diſcours ſur l'horlogerie, et expoſition d'une nouvelle méchanique de pendule, approuvée par Meſs. de l'Académie Roy. des Sci. par le ſieur *Mazurier.* 1756.

Jul. Le Roy anweiſung die einfachen ſowohl als Repetiruhren wohl einzurichten und zu gebrauchen. Dreſden. 1759.

L'art de conduire et de régler les pendules et les montres, &c. par M. *Ferdinand Berthoud.* 1759.

Molitor's anweiſung, wie Geh-, Schlag-, Repetir-, und Sackuhren richtig berechnet, probirt und traktirt werden. Frankfurt am Mayn. 1762.

Eſſai ſur l'horlogerie, dans lequel on traite de cet art relative-

ment à l'uſage civil, à l'aſtronomie, et à la navigation, en établiſſent des principes confirmés par l'experience, par *Fer. Berthoud.* 1763.

Elements of clock and watch work, by *Alexander Cumming.* 1766.

An account of the going of Mr. Harriſon's watch at the Royal Obſervatory from May 5th, 1766, to March 4th, 1797. Together with the original obſervations and calculations of the ſame. By the rev. *Nevil Maſkelyne*, aſtronomer royal, &c. 1767.

Principles of Mr. Harriſon's time-keeper, with plates of the ſame, publiſhed by order of the commiſſioners of longitude. 1767.

Remarks on a pamphlet lately publiſhed by the reverend Mr. Maſkelyne, by Mr. *Harriſon.* 1768.

A deſcription concerning ſuch mechaniſm as will afford a nice or true menſuration of time, by *John Harriſon.* 1775.

Eſſay de la montre marine de M. *le Roy*, mem. Roy. Acad. 1767.

Relation du voyage de M. *Caſſini*, fils, fait par ordre du roi, pour examiner les montres marines de M. *le Roy*, l'ainé, mem. Roy. Acad. 1769.

Suite du précis ſur les montres marines, avec un ſupplement au mémoire ſur la meilleure manière de meſurer le tems au mer, par M. *le Roy*, à Leyd. 1776.

Recherches ſur le vrai moyen de perfectionner les pendules à ſecondes, deſtinés à indiquer les équations journalières du ſoleil, &c. par le ſieur *Ridereau.* 1770.

On the going of Mr. Arnold's pocket chronometer made on a new conſtruction, by Dr. *N. Maſkelyne.* 1770.

Deſcription nouvelle de la cathédrale de Straſbourg, et de la fameuſe tour, par M. *Joſeph Schweighaeuſer.* 1770.

D'une montre particulière, nommée almanach en montre, ou montre à la Jablonowſky, par M. *Paſſament.* 1770.

Steph. Ramouſki experimenta circa longitudinem penduli ſimplicis minuta, ſecunda, Kolae et Archangelopoli oſcillantis. Nov. Com. Acad. Petrop. 1771.

Traité des horloges marines, contenant la théorie, la conſtruction, la main-d'œuvre de ces machines, et la manière de les éprouver, pour parvenir par leur moyen à la rectification des cartes marines, et à la determination des longitudes, &c. par M. *Ferdinand Berthoud.* 1773, et 1792.

Eclairciſſemens ſur l'invention, la théorie, la conſtruction, et les épreuves des nouvelles machines propoſées en France pour la determination des longitudes en mer par le meſure du tems, par M. *Ferd. Berthoud.* 1773.

Rapport fait à l'Académie des Sciences par Meſſrs. *Montigni*

et *Vaucanſon*, ſur un nouvel échappement à détente, imaginé et préſenté par M. *Platier*, horloger et méchanicien de S. A. S. Monſeigneur le Prince de Conti. 1774.

Leonh. Euler, de oſcillationibus minimis penduli quotcunque ponduſculis onuſti. Nov. Com. Acad. Petrop. 1775.

Leonh. Euler, de motu oſcillatorio binarum lancium ex libra ſuſpenſarum. Nov. Com. Ac. Petrop. 1775.

Dan. Bernoulli commentatio phyſico-mechanica, &c. Nov. Com. Acad. Petrop. 1775.

Reflexions ſur l'échappement, par M. *de la Grange*, mem. Acad. Berlin. 1777.

Dan. Bernoulli ſpecimen philoſophicum de compenſationibus horologicis et veriori menſuria temporis. Act. Acad. Imp. Petrop. 1777.

Lettre de M. *Magellan* à M. le chevalier *de Bory*, de l'Académie Royale des Sciences, rélativement à la montre marine de M. *Mudge*, éleve du célébre Graham, et l'un des plus habiles horlogers de ce ſiècle.

[This is inſerted in *Rozier*'s Obſervations ſur la phyſique, ſur l'hiſtoire naturelle, et ſur les arts, tom. xi. 1778.]

Abraham Gotthelf Käſtner, über die Aenderung des Ganges der Pendeluhren un Sommer und Winter. Gottingen. 1778.

Various papers relative to the contrivances in watch-work, by *François Arlaud*, *François Callet*, &c. in the Mémoires de la ſociété établie à Genève pour l'encouragement des arts et de l'agriculture, tom. i. ii. &c. 1778.

Leonhard Euler de motu oſcillatorio pendulorum ex filo tenſo dependentium. Act. Acad. Imp. Petrop. 1779.

Deſcription d'une machine pour refendre pluſieurs roues d'horlogerie en même temps, inventée par M. *Pingeron*, capitaine de l'artillerie, &c. 1780.

Balancier de pendule à ſecondes d'une nouvelle conſtruction, par le ſieur *Grenier*. Rouen. 1780.

L'art de faire les reſſorts de montres, ſuivi de la manière de faire les petits reſſorts de répétitions et des reſſorts ſpiraux, par *W. Blakey*. Amſterdam. 1780.

A letter from Mr. *Chriſtian Mayer*, aſtronomer to the elector palatine, to Mr. N. N. on the going of a new pendulum clock, made by Mr. *John Arnold*, and ſet up in the elector's obſervatory at Manheim. (Tranſlated from the German.) London, Becket. 1781.

Der neue engliſche Uhrmacher, oder vollſtändige Anweiſung alle Geh-, Schlag-, und Repetiruhren richtig zu berechnen und gehörig zuſammenzuſetzen, nebſt der Beſchreibung einer Univerſal-Sonnenuhr, mit nöthigen Kupfern, &c. 1781.

Extrait d'une lettre de M. *L. H. Magellan* à un de ſes amis de Paris, ſur la préférence des grand arcs de vibration pour le

régularité des pendules aſtronomiques, avec la deſcription d'un échappement libre, pour des petites pendules à demiſecondes, qui battent des ſecondes entières. [This is inſerted in tom. XX. of Rozier's Obſervations, &c. 1782.]

Nic. Fuſs Determinatio motuum penduli compoſiti bifili ex primis mechanicæ principiis petita. Nov. Act. Petrop. tom. I. 1783.

Leonh. Euler De motu oſcillatorio, &c. Nov. Act. Petrop. tom. I. 1786.

Three regiſters of a pocket chronometer, by count de *Brühl*. 1785.

Mémoire ſur l'horlogerie; contenant une nouvelle conſtruction des montres ſimples et à repetition à roues de rencontre, approuvées par l'Acad. Roy. des Sciences. Par *Heſſen*. 1785.

Der ſelbſtlehrende uhrmacher, oder genugthuende anweiſung, alle ſchlag-, geh-, repetir-, und ſonnen-uhren richtig zu berechnen, nebſt allen vortheilen, auf die neueſte und einfachſte art ſie zu verfertigen ohne einen weitern mündlichen unterricht nöthig zu haben. Von einem Freunde der Künſte. 1786.

Deſcription of the two-part chime-clock invented by *Robert Sampſon*. Tranſactions of the Society for the Encouragement of Arts, &c. for 1786, vol. iv. [Deſcriptions of many other ingenious inventions of Engliſh artiſts may likewiſe be found in the different volumes of the Tranſactions of this reſpectable and uſeful ſociety.]

An account and deſcriptions of three pendulums invented and conſtructed by *John Croſthwaite*. Trans. Roy. Iriſh. Acad. 1788.

Horlogerie pratique à l'uſage des apprentifs et des amateurs. par M. *Vioniaux*, à Toulouſe. 1788.

Tratado general y matematico de la reloxeria, que comprende el modo ex hacer reloxes de todas claſſes, y del de ſaberlos componer y arreglar por dificiles que ſean; acompanado de los elementos neceſſarios para ella. Su autor *Em. de Cercella é Icoaga*. Madrid. 1789.

Sopra la teoria de pendoli e ſulla legge della forza centripeta proporzionale alla ſemplice diſtanza del centro e ſulla ſua applicazione alla dottrina de' pendoli; diſcorſi del ſign. *Gregorio Fontana*. Pavia. 1789.

Whitehurſt's Verſuch durch zeitmeſſung unveränderliche maſſe zu erhalten; uberſetzt von *J. H. Wiedmann*. Nürnberg. 1790.

Diſſertation ſur l'horlogerie, par *Fr. Huet*. 1791.

Tratado methodico de la reloxeria ſimple; eſcr. por *Ph. y Pl. Chaboſt*. Madrid. 1791.

Der uhrmacher, &c. von *J. G. Geiſsler.* 1793-1799.

Account of a new pendulum, by *Geo. Fordyce*, M. D. F.R.S. *Phil. Trans.* 1794. Part I.

Inveſtigations, founded on the theory of motion, for determining the times of vibrations of watch balances, by *Geo. Atwood*, F.R.S. Phil. Trans. 1794. Part I.

Beytrag zur zeitmeſs kunſt fur freunde und liebhaber von uhrwerken aller art. Von *Friedrich Auguſt Schmidt.* Leipzig. 1797.

Suite du traité des montres à longitudes, &c. par *F. Berthoud.* 1797.

Verſuch einer geſchichte der entſtlehung und fortſchritte der theoretiſch-praktiſchen uhrmacherkunſt. Von *Joh. Heinr. Mortitz Poppe.* Gottingen. 1797.

Theoretiſch-praktiſches worterbuch der uhrmakerkunſt, &c. Von *J. H. M. Poppe.* 1799-1800. Leipzig.

Ausführliche geſchichte der theoretiſch-praktiſchen uhrmacherkunſt, &c. Von *J. H. M. Poppe.* Leipzig. 1801.

[The two latter are deemed to be very valuable performances.]

The article WATCHWORK in the Supplement to the *Encyclopædia Britannica*, and different parts of *Nicholſon*'s Philoſophical Journal, and *Tilloch*'s Philoſophical Magazine, contain much uſeful information on the ſubjects of pendulums, ſcapements, &c.

COINAGE, or COINING, the art or act of making money.

Coining is either performed by the hammer or the mill. The firſt method is now little uſed in Europe, eſpecially in England, France, &c. though the only one known till the year 1553, when a new machine, or coining mill, invented by an engraver, one Antoine Brucher, was firſt tried in the French king's palace at Paris, for the coining of counters: though ſome attribute the invention of the mill to Varin, a famous engraver, who, in reality, was no more than an improver of it; and others to Aubry Olivier, who had only the inſpection of it.

The mill has met with various fate ſince its firſt invention; being now uſed, and again laid by, and the hammer reſumed; but it has at length got that footing, by the neatneſs and perfection of the ſpecies ſtruck with it, that there appears no great probability of its ever being again diſuſed.

In either kind of coining, the pieces of metal are ſtamped or ſtruck with a ſort of punchions or dyes, wherein are engraven the prince's effigies, with the arms, legend, &c.

Coining by the mill, or milled money.—The bars or plates being taken out of the mould, and ſcraped and bruſhed, are paſſed ſeveral times through a mill, to flatten them further, and bring them to the juſt thickneſs of the ſpecies to be coined; with this difference, however, that the plates of gold are heated again in a furnace, and quenched in water, before they undergo the mill; which ſoftens and renders them more ductile; whereas thoſe of ſilver paſs the mill juſt as they are, without any heating; and when afterwards they are heated they are left to cool again of themſelves, without water.

The plates, whether gold, ſilver, or copper, thus reduced as near as poſſible to their thickneſs, are cut into round pieces, called blanks or planchets, near the ſize of the intended ſpecies, with a cutting inſtrument faſtened to the lower extremity of an arbor, whoſe upper end is formed into a ſcrew; which, being turned by an iron handle, turns the arbor, and lets the ſteel, well ſharpened, in form of a punch-cutter, fall on the plates; and thus is a piece punched out.

Theſe pieces are now given to be adjuſted, and brought by filing, or raſping, to the weight of the ſtandard, whereby they are to be regulated: and what remains of the plate between the circles is melted again, under the denomination of ſizel.

The pieces are adjuſted in a fine balance: and thoſe which prove too light are ſeparated from thoſe too heavy; the firſt to be melted again, and the ſecond to be filed down. For it may be obſerved, that the mill through which the plates are paſſed can never be ſo juſt but there will be ſome inequality, whence will ariſe a difference in the blanks. And this inequality, indeed, may be owing to the quality of the matter as well as of the machine; ſome parts being more porous than others.

When the blanks are adjuſted they are carried to the blanching or whitening-houſe, i. e. the place where the gold blanks have their colour given them, and the ſilver ones are whitened; which is done by heating them in the furnace, and, when taken out and cooled, boiling them ſucceſſively in two copper veſſels, with water, common ſalt, and tartar; and, after that, ſcouring them well with ſand, and waſhing them with common water, drying them over a wood fire, in a copper ſieve, wherein they are put when taken out of the boilers.

Formerly the planchets, as ſoon as blanched, were carried to the preſs, to be ſtruck, and receive their impreſſions; but now they are firſt marked with letters or graining on the edges, to prevent the clipping and paring of the ſpecies, which is one of the ways wherein the ancient money uſed to be damaged. The machine uſed to mark the edges is very ſimple, yet ingenious; it conſiſts of two plates of ſteel, in form of rulers, about the thickneſs of a line, on which the legend or edging is engraven, half on the one, and half on the other. One of theſe plates is immoveable, being ſtrongly bound with ſcrews to a copper plate; and that again to a ſtrong board, or table: the other is moveable, and ſlides on the copper plate by means of a handle, and a wheel, or pinion of iron, the teeth whereof catch in a kind of other teeth, on the ſurface of the ſliding plate. Now, the planchet, being placed horizontally between theſe two plates, is carried along by the motion of the moveable one; ſo as by that time it has made half a turn it is found marked all round. See fig. 1. pl. XIV.

This machine is ſo eaſy, that a ſingle man is able to mark twenty thouſand planchets in a day. Savang pretends it was invented by the ſieur Caſtagin, engineer to the French king, and firſt uſed in 1685. But it is certain we had the art of lettering the edges in England long before that time; witneſs the crowns and half-crowns of Oliver Cromwell ſtruck in 1658, which for beauty and perfection far exceed any French coins we have ever ſeen.

Laſtly, the planchets, being thus edged, are to be ſtamped, i. e. their impreſſion is to be given them in a ſort of mill, or preſs, by the French called a balancier, invented towards the latter end of the ſixteenth century. See its figure in fig. 2. pl. XIV.

Its chief parts are a beam, ſcrew, arbor, &c. all contained in the body of the machine, except the firſt, which is a long iron bar, with a heavy ball of lead at each end, and rings, to which are faſtened cords, which give it motion: this is placed horizontally over the body of the machine. In the middle of the beam is faſtened a ſcrew, which, by turning the beam, ſerves to preſs the arbor underneath it; to the lower extremity of which arbor, placed perpendicularly, is faſtened the dye, or matrice, of the reverſe, or arm ſide, in a kind of box, or caſe, wherein it is retained by ſcrews: and under this is a box, or caſe, containing the dye of the image-ſide, firmly faſtened to the lower part of the engine, fig. 3.

Now when a planchet is to be ſtamped it is laid on the image-matrice, upon which two men draw, each on his ſide, one of the ropes of the beam, and turn the ſcrew faſtened in it; which by this motion lowers the arbor to which the dye of the arms is faſtened: by which means the metal being in the middle, at once receives an impreſſion on each ſide, from either dye. As to the preſs formerly uſed, it has all the eſſential parts of a balancier, except the beam, which is here, as it were, divided, and only drawn one way.

The blanks having now all their marks and impreſſions, both on the edges and faces, become money; but they have not currency till they have been weighed and examined.

For the Coining of Medals the progreſs is the ſame, in effect, with that of money: the principal difference conſiſts in this, that money, having but a ſmall relievo, receives its impreſſion at a ſingle ſtroke of the engine; whereas, for medals, the height of their relievo makes it neceſſary that the ſtroke be repeated ſeveral times: to this end the piece is taken out from between the dyes, heated, and returned again; which proceſs, in medallions, and large medals, is ſometimes repeated fifteen or twenty times, before the full impreſſion be given; care being taken, every time the planchet is removed, to take off the ſuperfluous metal ſtretched beyond the circumference, with a file.

An improvement has been lately ſuggeſted in the coining-preſs, by a Mr. Huigenan, we believe, who has introduced the principle of the heart-wheel both in this contrivance and in his univerſal lever. The method Mr. H. recommends may be underſtood by referring to fig. 4. pl. XIV. CB is part of a table or plane on which is fixed the box containing the dye F of the image ſide of the coin, and CA is a lever to which is attached the dye E of the reverſe ſide in a caſe retained by ſcrews; and this is ſo poſited, that by turning CA on the centre C the parts E and F may be brought the one immediately above the other. G is an elliptical or heart-wheel turning upon a fixed centre by the handle or winch H, and, acting upon the friction wheel D, gradually forces down the end A of the lever, and carries with it the dye E, cauſing it to preſs very hard upon the metal placed on the lower dye F, at the time the extremity I of the elliptical wheel is in contact with the upper part of the wheel D. Then the motion of the winch proceeding, the ſpring S raiſes up the lever CA, and thus leaves room to remove the metal: place another at F, and repeat the operation. The whole, it is obvious, may be carried on with conſiderable expedition; but whether the method is on the whole preferable to that before deſcribed is what we do not here attempt to decide.

COMPASSES (BEAM), a kind of compaſſes uſed to draw large arcs, and to take large extents, &c. Theſe compaſſes conſiſt of a ſtraight beam or bar, of 18 inches, 2 feet or more in length, carrying two braſs curſors; one of theſe being fixed at one end, the other ſliding along the beam, with a ſcrew to faſten it on occaſionally. To the curſors may be ſcrewed points of any kind, as of ſteel, braſs, pencils, &c. The fixed curſor has ſometimes an adjuſting or micrometer ſcrew applied to it, for the more nice obtaining of extents.

The beam is divided commonly into inches, tenths, and half tenths: but Mr. Walton, an ingenious mechanic, in the proof department of the Royal Arſenal, Woolwich, has improved this inſtrument and much extended its utility, by applying a nonius to its ſcale, which renders it fit to take diſtances to hundredth parts of an inch. Part of a beam with the additions of Mr. Walton are ſhewn in fig. 1. pl. XVIII. where IK repreſents more than 4 inches in length of a beam, which is made of ebony, the diviſions being marked upon braſs laid into the ebony. ABCD and EFGH are two braſs caſes which nearly fit the beam, and may ſlide to and fro upon it: theſe braſs caſes carry the curſors and points L and M, which are faſtened into ſockets by means of ſcrews at N and O. The caſe ABCD has two ſcrews *b c* and *a*, both of which are turned by means of forked turnſcrews: the firſt of theſe ſcrews, *b c*, ſerves to move the braſs caſe backwards and forwards on the beam, in order to adjuſt the point L ſo as to correſpond with the commencement of the diviſions on the beam; and when that is done the ſcrew *a*, by preſſing a ſpring, makes the whole faſt to the beam. The other braſs caſe EFGH carries the curſor and point M, as well as the moveable nonius *e i*: this nonius is at the extremity of a piece *e f g h k i*, which is moved to and fro upon the caſe EFGH by means of the ſcrew *o p q s*, which is turned by the milled head *r s t*: the ſhoulders at *p* and *q* prevent the ſcrew from moving either backward or forward with reſpect to the line FH, while the threads of the ſcrew between *o* and *p*, by taking upon the moveable piece *e f g h k i*, cauſe the nonius to move along the edge of the graduated ſcale of the beam: turning the head of the ſcrew in the dreċtion *r s t* moves the nonius in the direction from K towards I on the beam; and turning that head in the direction *t s r* advances the nonius according to the increaſing meaſure upon the ſcale from I towards K. The ſcrew *d* with its milled head P, by preſſing upon a ſpring, will at any time make the caſe EFGH faſt to the beam, and thus prevent, when neceſſary, any change of diſtance between L and M. Fig. 2. is a tranſverſe ſection of the braſs caſe EFGH: it ſerves to ſhew the form 1, 2, 3, 4, 5, of the beam, bevelled off to an edge at 4; alſo the bevel of the nonius at *e*; the dovetail at *q*, againſt which one ſhoulder of the micrometer ſcrew preſſes; and the piece *f v*, into which the three ſcrews *l*, *m*, *n* (fig. 1.) enter. Other parts of the conſtruction will be ſufficiently obvious from theſe figures.

CONDENSER, a pneumatic engine or ſyringe, by which an extraordinary quantity of air may be crowded or puſhed into a given ſpace; ſo that frequently ten times as much air as an equal ſpace would contain out of the engine may be thrown in by means of it, and its egreſs prevented by valves properly diſpoſed.

The condenſer is made either of metal or of glaſs, and either in a cylindrical or globular form; and the air is forced into it by an injecting ſyringe. The receiver, or veſſel containing the condenſed air, ſhould be made very ſtrong, to bear the force of the air's elaſticity thus increaſed: for which reaſon it is commonly made of braſs. When glaſs is uſed it will not ſuſtain ſo great a condenſation of air; but the experiment will, notwithſtanding, be rendered more entertaining, as the effect of the condenſed air upon any ſubject put within the receiver may be viewed through the glaſs.

Condenser *of Forces*, a name given by M. Prony to a contrivance for obtaining the greateſt poſſible effect from a firſt mover, the energy of which is ſubject to augmentation or diminution within certain limits; and in general to vary at pleaſure the reſiſtance to which the effort of the firſt mover forms an equilibrium in any machine whatever, without changing any part of their conſtruction.

The general problem in mechanics, of which this condenſer is intended as a practical ſolution, is enunciated by M. Prony in theſe terms:

"Any machine being conſtructed, to find, without making any change in the conſtruction, a means of tranſmitting to it the action of the firſt mover, by fulfilling the following conditions; viz.

"1. That it may be poſſible at pleaſure, and with great ſpeed and facility, to vary the reſiſtance (againſt which the effort of the firſt mover muſt continually make an equilibrium) in limits of any required extent.

"2. That the reſiſtance, being once regulated, ſhall be rigorouſly conſtant until the moment when it is thought proper to increaſe or diminiſh the ſame.

"3. That in the moſt ſudden variations of which the effort of the firſt mover may be capable, the variation in velocity of the machine ſhall never undergo a ſolution of continuity."

M. Prony applies his ſolution of this problem to the dynamic effect of wind: it will be eaſy to make the ſame general when the other firſt movers are uſed.

The ſection and plan of the machine are exhibited in plate XIV. OO repreſents the vertical arbor to which windmill ſails are adapted; *e e e e* is an aſſemblage of carpentry, of which one of the radii, O *e*, bears a curved piece, *b d*, of iron or ſteel: vertical axes of rotation *a a a*, being placed round the axis OO, alſo divide the circumference in which they are found into equal parts.

Each of theſe axes carries a curve, *a f*, of iron, ſteel, or copper; ſo ſituated, that when the wind acts upon the ſails the curve *b d* preſſes againſt one of the curves *a f*, and cauſes the vertical axis to which this laſt curve is fixed to make a portion of a revolution.

The curves *b d* and *a f* muſt be ſo diſpoſed, that when *b d* ceaſes to preſs on one of the curves *a f*, it ſhall at the ſame inſtant begin to act upon the following curve: the number of axes which are provided with theſe curves muſt be determined by the particular circumſtances of each caſe; and it is alſo practicable to ſubſtitute, inſtead of *b d*, a portion of a toothed wheel having its centre in the axis OO, and to place portions of pinions inſtead of the curves *a f;* but the diſpoſitions repreſented in the figure are preferable.

Each of the axes *a a a a* (which are all fitted up alike, though, for the ſake of clearneſs, only one of them has its apparatus repreſented in the drawing), carries upon it a drum or pulley *t t r r*, on which is wound a cord that paſſes over a pulley *p*, and ſerves to ſupport a weight Q by means of the lever FG, upon which this weight may be ſlided and faſtened at different diſtances from the point of motion G.

The ſame axes *a a* paſs through the pinions *q q*, to which they are not fixed; but theſe pinions carry clicks or ratchetts, which bear againſt the teeth *r r;* ſo that, when the weight Q tends to riſe, the ratchett gives way, and no other effect is produced on the pinion *q q*, either by the motion of the axis or of the drum *t t r r*, excepting that which cauſes the aſcent of the weight *q q*. But the inſtant that the curve or tooth *b d* ceaſes to bear againſt one of the curves *a f*, after having cauſed the correſponding weight Q to riſe, that weight Q tends to redeſcend, and then the toothed wheel *r r* acts againſt the ratchett, ſo that Q cannot deſcend without turning the pinion *q q* along with the drum *t t r r*.

The pinion *q q* takes in the wheel *a b*, from the motion of which the uſeful effect of the machine immediately reſults; ſo that the effect of the deſcent of one of the weights Q is to ſolicit the wheel AB to motion, or to continue the motion in concurrence with all the other weights Q, which deſcend at the ſame time. This wheel AB carries beneath it oblique or bevelled teeth GD, which take in a like wheel CE, and cauſe the buckets at S to riſe.

From the preceding deſcription it is ſeen that the machine, being ſuppoſed to ſtart from a ſtate of repoſe, the wind will at firſt raiſe a number of weights Q, ſufficient to put the machine into motion, and will continue to raiſe new weights while thoſe before raiſed are fallen; ſo that the motion once impreſſed will be continued.

Among the numerous advantages of this new mechaniſm we may remark the following:

1. No violent ſhock can take place in any part of the mechaniſm.

2. The uſeful effect being proportioned to the number of

weights Q, which deſcend at the ſame time, this effect will increaſe in proportion as the wind becomes ſtronger, and cauſes the ſails to turn with more velocity.

3. The weights Q being moveable along the levers FG, it will always be very eaſy to place them in ſuch a manner as to obtain that ratio of the effort of the firſt mover to the reſiſtance which will produce the maximum of effect.

4. From this property it reſults that advantage may be taken of the weakeſt breezes of wind, and to obtain a certain product in circumſtances under which all other windmills are in a ſtate of abſolute inactivity. This advantage is of great importance, particularly with regard to agriculture: the windmills employed for watering lands are ſometimes inactive for ſeveral days, and this inconvenience is more particularly felt in times of drought. A machine capable of moving with the ſlighteſt breeze muſt therefore offer the moſt valuable advantages.

CRAB or GIN, an engine uſed for mounting large guns on their carriages, &c. It is compoſed of three long and ſtout legs, meeting together at their tops; theſe legs are round poles of about 12 or 13 feet long, whoſe diameters at the lower end are about four inches, five juſt below the roller, beſides the cheeks that are added to them in that place, and about 3½ inches above.

Two of theſe poles can be fixed at a certain diſtance from each other, by means of two iron bars placed horizontally, one being about four feet long, the other about ſeven; and a roller is made to run upon pivots turning on, or in, theſe two poles: this roller is commonly 7½ inches in diameter, and ſix feet long. A portion of 20 inches is left ſquare at each end, and holes made in each to receive the handſpikes by which the men turn the roller: but the middle part is made cylindrical, to wind the cable upon. The tranſverſe iron bars are fixed with one end to one of the poles by means of a bolt, and with the other end to the other pole with a bolt and key; ſo as to be readily taken out, in order that when the gin is to be removed from place to place the poles may lie cloſe together upon the carriage. There are two iron bands and two iron bolts to faſten each cheek (for the pivots) to the poles, and iron plates round the poles where the iron bars are fixed. The poles are hooped at each end; and the upper ends have ſtraps through which an iron bolt paſſes: this bolt keeps the upper ends together, as well as ſerves to ſupport the iron to which the windlaſs is hooked. The windlaſs contains two braſs pullies, about which the cable goes, which is fixed to the dolphins of the gun or mortar with another windlaſs, containing two braſs pullies likewiſe. When this machine is uſed the whole is laid flat on the ground, the lower end of the ſingle pole extending the contrary way, in order to faſten the upper windlaſs after the cable has been turned round both: after this the upper end is raiſed gradually till the feet of the three poles (each of which has an iron prong) ſtand nearly at equal diſtances; in ſuch a manner as the legs of a theodolite or plain table, when ſet up for uſe in the practice of ſurveying.

CRANE, a machine uſed in building, on wharfs, and in warehouſes, for raiſing and lowering huge ſtones, ponderous weights, packages, &c.

1. Cranes until of late years were commonly conſtructed as follows: the principal member is a ſtrong upright beam or arbor, firmly fixed in the ground, and ſuſtained by eight arms, coming from the extremities of four pieces of wood laid acroſs, through the middle of which paſſes the foot of the beam. About the middle of the arbor the arms meet, and are mortiſed into it: its top ends in an iron pivot, on which is borne a tranſverſe piece, advancing out to a good diſtance, ſomething after the manner of a crane's neck, whence the machine has its name. This projecting piece is now more commonly called the jib or gibbet. The middle and extremities of this are again ſuſtained by arms from the middle of the arbor: and over it comes a rope or cable, to one end of which the weight is fixed; the other is wound about the ſpindle of a wheel, which when turned (commonly by means of men walking upon the inſide of the rim of the wheel) draws the rope, and that heaves up the weight; which may afterwards be applied to any ſide or quarter by the mobility of the tranſverſe piece on the pivot. Theſe cranes have uſually been made of two kinds: in the firſt, called the rat-tailed-crane, the whole machine with the load turns upon a ſtrong axis: in the ſecond kind the gibbet alone moves on its axis. But in either kind, if the machinery be put into motion by men walking *within* the wheel, as has been till lately the nearly univerſal practice in this country, the labourers employed are expoſed to extreme danger, and have frequently met with the moſt ſhocking and fatal accidents. It is not then to be wondered at, that ſkilful mechaniſts ſhould at length have deviſed cranes that are not only more ſafe, but more powerful in their operations, than the common walking crane: a few of the beſt of theſe will be deſcribed in the preſent article.

2. The late Mr. Ferguſon invented a crane which has three trundles, with different numbers of ſtaves, that may be applied to the cogs of a horizontal wheel with an upright axle; round which is coiled the rope that draws up the weight. This wheel has 96 cogs; the largeſt trundle 24 ſtaves, the next 12, and the ſmalleſt 6, ſo that the largeſt revolves 4 times for one revolution of the wheel; the next 8, and the ſmalleſt 16. A

winch is occaſionally fixed on the axis of either of theſe trundles for turning it; and is applied to the one or the other according as the weight to be raiſed is ſmaller or larger. While this is drawing up, the ratch-teeth of a wheel ſlip round below a catch that falls into them, prevents the crane from turning backwards, and detains the weight in any part of its aſcent, if the man who works at the winch ſhould accidentally quit his hold, or wiſh to reſt himſelf before the weight is completely raiſed. Making a due allowance for friction, a man may raiſe by ſuch a crane from three times to twelve times as much in weight as would balance his effort at the winch; viz. from 90 to 360lbs. taking the average labour.

Other ingenious contrivances by Mr. Ferguſon may be ſeen in his *Select Exerciſes*; but as the book is in the hands of almoſt every practical mechanic, we would rather refer to it than extract accounts of theſe inventions.

3. The crane preſented in plate VII. is a portable one, mounted in a wooden frame and ſtage, which is judged to be very uſeful for loading and unloading carts with large heavy ſtones. It is moveable to any part of a ſtone-yard or ground; the frame is ſufficiently wide for a cart to draw under the crane, and at any time it may be taken to pieces. The frame AAAA is made of wood, is about 9 or 10 feet high, and about 9 feet ſquare. The wheels BB are of iron, and are about 3 feet in diameter; and the pinion D, that is fixed to the axis of the firſt wheel B,, 8 inches in diameter: on the axis of the ſecond wheel B the axis round which the rope coils is fixed. Now the ſtone being corded and hooked at the end of the rope, it is very evident that the man at C will either raiſe or lower them as may be neceſſary, according as he turns the winch towards or from him, and in a ſafe and very eaſy manner. The advantage in point of power being in proportion as the product of the radii of the wheels to thoſe of the pinions.

4. Fig. 7. pl. XII. is a repreſentation of a crane-carriage which Mr. Gottlieb conceives to be very uſeful in moving large ſtones in quarries, where carts and horſes cannot be conveniently or at all managed. Its principle is evidently clear from a bare view of the figure. It conſiſts only of two ſets of crane-wheels applied to the two ſets of wheels belonging to the carriage; ſo that two men, one at each winch AA, turning the pinions and wheels round, ſhall act upon the carriage-wheels and move it along. By their both turning forwards or backwards, the carriage goes accordingly; but if they turn contrary ways, the carriage will be turned round, or partly ſo, as may be wanted. The pinion B is 6 inches in diameter, which turns the wheel C of

3 feet diameter, on the axis of which is fixed the pinion D of 1 foot diameter, which works into 2 wheels E, E, of 3 feet 6 inches diameter, that are fixed upon the carriage-wheels, and give motion to the whole machine.

5. Mr. *Abraham Andrews*, of Higham Ferrers, in Northamptonſhire, has invented a crane which weighs the body ſuſpended at the time it is raiſing: an improvement for which the Society for the Encouragement of Arts, &c. granted him a premium of 15 guineas. This crane is ſhewn in fig. 3. pl. IX. The jib of the crane ſtands on a horizontal beam, moveable on a centre at A: and the diſtance of the centre A, from the bearing of the upright, being to the diſtance B, in proportion of 1 to 20, the weight placed at B determines that of the body ſuſpended in the ſame proportion. C is a ſtub, or piece of wood, which projects from the weight hanging at the end of the jib, and ſerves to prevent the beam from riſing to too great a height.

This jib ſhould be placed in the ſame vertical plane with the part BA of the crane, at the time the weight is adjuſted; otherwiſe it will occaſion a friction which may prevent the moveable beam from playing freely. The other parts of the crane are ſo obvious in their conſtruction as not to require a more minute deſcription.

6. The ſociety juſt mentioned have lately voted 40 guineas to Mr. *Robert Hall*, jun. of Basford, near Nottingham, for his ingenious invention of a method to expand a ſet of bars parallel to the axis of a crane, by which means the velocity of the rope in raiſing weights may be increaſed or diminiſhed in proportion to the load to be raiſed.

A deſcription and engraving of this crane are given in the twelfth volume of the Society's Tranſactions, from which we have drawn up the following account of it:

The ends of the reel (fig. 1. and 5. plate III.) conſiſt each of two flat plates or circular pieces, ſhewn ſeparately in fig. 2. and 3. Theſe circular plates form the two ends of the reel, and are held faſt on the ſpindle or axis by pins paſſed through its ends, of which one may be ſeen at *a*, fig. 2. and another in the end ſhewn in fig. 5. The outer circular plate (fig. 3.) of each end of the reel has a ſpiral groove cut in it, as ſhewn at *b*; and the inner circles have each eight mortices cut quite through them, as ſhewn at *c*, fig. 2. (ſeen partly alſo in fig. 1. and 5.) The outer plates have alſo an iron tube, *d*, made faſt to them by means of a flange or collar, and the ſcrews, *ee*, fig. 2.

When the parts are all joined (as ſhewn in fig. 1.), the axis *f* paſſes through the tube *d*, and thus the ends are connected. In fixing the croſs bars, two of which are ſhewn detached in fig. 4., the parts *g g* ſlide in the mortices *c* of the inner circular plates, and the ſmall ends or tenons *h h* go fairly through the inner and enter the ſpiral grooves of the outer plates.

The inner and outer circular plates are locked together by a catch (*i*, fig. 1. 2. and 6.) the ſtationary part of which is made faſt to the inner plate (ſee fig. 2.), while the catch itſelf, by means of a ſpring, is kept in a notch on the edge of the outer plate. When the diameter of the reel is to be enlarged or diminiſhed, it is effected by bringing the reel round to the poſition ſhewn in fig. 6., when a hook *k* is put into a hole *l*, which keeps the inner circular plate in that poſition till the adjuſtment is made by lifting the catch from the notch of the outer end-plate far enough to be kept diſengaged by the hook *k*, before mentioned, being thruſt quite through the hole *l*: the handle *m* being then turned, the outer plate only is carried round, and the tenons or ſmall ends of the croſs bars (being prevented from being carried round with it, by the mortices of the inner plates through which they paſs being ſtationary) are obliged to change their diſtance from the axis by the ſpiral groove ſliding over them, while they are able to move nearer or further from the axis by ſliding in the radial mortices of the inner end plate.

The handle *m* being turned till the reel is of the ſize required, the hook *k* is withdrawn or puſhed out, and the crane is then ready for work.

It is neceſſary to obſerve that the tenons *h h* muſt be cut, ſo that the outſide of all the bars next the rope ſhall be at an equal diſtance from the centre. If the tenon of the firſt bar that is placed in the reel be cut like the tenons *h h*, fig. 4. the laſt of them muſt be cut the ſame as the tenons *n n*, fig. 4.; and all the other tenons, at the extremities of the ſeveral bars, muſt be at proper diſtances between theſe extremes, as is ſhewn by the dots P in the mortices fig. 2.

The other parts of the crane may be ſo eaſily underſtood from an inſpection of the engraving, that any further deſcription is unneceſſary. Phil. Mag. No. 71.

7. But the ſeveral cranes deſcribed in this article as preferable to the common walking-crane, while they are free from the dangers attending that machine, loſe at the ſame time one of its advantages; that is, they do not avail themſelves of that addition to the moving power which the *weight* of the men who are employed may furniſh. Yet this advantage has been long ſince enſured by the mechaniſts on the continent, who cauſe the labourers to walk upon an inclined plane, turning upon an axis, after the manner ſhewn in the figure referred to under the article *Footmill*, where we have deſcribed a contrivance of that kind, well known in Germany nearly 150 years ago. The

ſame principle has been lately brought into notice, probably without knowing it had ever been adopted before, by Mr. *James Whyte*, of Chevening, in Kent: his crane is exhibited in fig. 3. and 4. pl. X. as it was deſcribed in the Tranſactions of the Society for the Encouragement of Arts.

A (fig. 3.) is a circular inclined plane, moving on a pivot underneath it, and carrying round with it the axis E. A perſon walking on this plane, and preſſing againſt the lever B, throws off the gripe D, by means of an iron rod C; and thus admits the plane and its axis to move freely, and raiſe the weight G by the coiling of the rope F round the axis E.

To ſhew more clearly the conſtruction and action of the lever and gripe, a plan of the circular inclined plane, with the lever and gripe, is added (ſee fig. 4.), where B repreſents the lever, D the ſpring or gripe. In this plan, when the lever B is in the ſituation in which it now appears, the ſpring or gripe D preſſes againſt the periphery of the plane, as ſhewn by the double line, and the machine cannot move; but when the lever B is preſſed out to the dotted line H the gripe is alſo thrown off to the dotted line I, and the whole machine left at liberty to move. One end of a rope or cord, of a proper length, is fixed near the end of the lever B, and the other end made faſt to one of the uprights, ſerving to prevent the lever moving too far when preſſed by the man.

The ſuppoſed properties of this crane, for which the premium of 40 guineas was adjudged by the ſociety to the inventor, are as follows:

1. It is ſimple, conſiſting merely of a wheel and axle. 2. It has comparatively little friction, as is obvious from the bare inſpection of the figure. 3. It is durable, as is evident from the two properties above-mentioned. 4. It is ſafe; for it cannot move but during the pleaſure of a man, and while he is actually preſſing on the gripe-lever. 5. This crane admits of an almoſt infinite variety of different powers, and this variation is obtained without the leaſt alteration of any part of the machine. If, in unloading a veſſel, there ſhould be found goods of every weight, from a few hundreds to a ton and upwards, the man that does the work will be able ſo to adapt his ſtrength to each as to raiſe it in a ſpace of time proportionate to its weight; he walking always with the ſame velocity as nature and his greateſt eaſe may teach him.

It is a great diſadvantage in ſome cranes, that they take as long time to raiſe the ſmalleſt as the largeſt weight, unleſs the man who works them turn or walk with ſuch velocity as muſt ſoon tire him. In other cranes, perhaps, two or three different powers may be procured; to obtain which, ſome pinion muſt be ſhifted, or freſh handle applied or reſorted to. In this crane, on the contrary, if the labourer find his load ſo heavy as to permit him to aſcend the wheel without its turning, let him only move a ſtep or two toward the circumference, and he will be fully equal to the taſk. Again, if the load be ſo light as ſcarcely to reſiſt the action of his feet, and thus to oblige him to run through ſo much ſpace as to tire him beyond neceſſity, let him move laterally towards the centre, and he will ſoon feel the place where his ſtrength will ſuffer the leaſt fatigue by raiſing the load in queſtion. One man's weight applied to the extremity of the wheel would raiſe upwards of a ton; and it need not be added, that a ſingle-ſheaved block would double that power. Suffice it to ſay, that the ſize may be varied in any required ratio; and that this wheel will give as great advantage at any point of its plane as a common walking-wheel of equal diameter, as the inclination can be varied at pleaſure, as far as expediency may require. It may be neceſſary to obſerve, that what in the figure is the frame, and ſeems to form a part of the crane, muſt be conſidered as a part of the houſe in which it is placed; ſince it would be moſtly unneceſſary ſhould ſuch cranes be erected in houſes already built. With reſpect to the horizontal part, by walking on which the man who attends the jib occaſionally aſſiſts in raiſing the load, it is not an eſſential part of this invention, where the crane is not immediately contiguous to the jib, although, where it is, it would be certainly very convenient and economical.

Notwithſtanding, however, the advantages which have been here enumerated, Mr. Whyte's crane is ſubject to this theoretical objection, that it derives leſs uſe than might be wiſhed from the weight of the man or men: for a great part of that weight (*half* of it, if the inclination be 30 degrees) lies directly upon the plane, and has no tendency to produce motion. Beſides, when this crane is of ſmall dimenſions, the effective power of the men is very unequal, and the barrel too ſmall for winding a thick rope: when large, the weight of the materials added to that of the men put it out of ſhape, and give it the appearance of a large, unwieldy, moving floor. We know one large crane of this conſtruction, which has an upright poſt near the rim on each ſide, to ſupport it and keep it in ſhape; and, as much as poſſible to prevent friction, each poſt had a vertical wheel at its top. We were informed this crane was ſeldom uſed, and that it was ſoon put out of order. Nor, moreover, is it every ſituation that will allow the crane-rope to form a right angle with the barrel on which it winds, and when this angle is oblique the friction muſt be much increaſed. The friction ariſing from the wheels at top of the vertical crutches might, indeed, be got ſhut of, by making the inclined wheel very ſtrong; but this would add greatly to the friction of the lower gudgeon of the oblique ſhaft, and conſiderably enhance the expence of the machine.

8. There remains, then, another ſtage of improvement with regard to the ſtructure of cranes, in which the weight of the labourers ſhall operate, without diminution, at the end of a *horizontal* lever; and in which the impulſive force thus ariſing may be occaſionally augmented by the action of the hands either in puſhing or lifting. This ſtep in the progreſs has been lately effected by Mr. *David Hardie*, of the Eaſt-India Company's Bengal warehouſe. After a few preliminary obſervations, we ſhall point out the diſtinguiſhing particulars of this gentleman's invention.

The capſtan, the wheel and pinion, with a winch, and the walking-wheel, are the cranes in common uſe at the preſent time; though a ſlight view of the method of working theſe machines might be ſufficient to ſhew that they are eſſentially defective in regard to the grand object in procuring the force of men, on which the quantity of work performed neceſſarily depends. The capſtan and walking-wheel call for little or no uſe of the arms; and the crane of the wheel and pinion derives very little advantage from the legs, while the force of the men acting upon the winch muſt of neceſſity be very fluctuating. At the capſtan, and wheel, and pinion, a conſiderable force is expended unproductively in giving action to the greater part of the men's weight, which does not contribute to the moving power of the machines; the power actually exerted ſeldom exceeding 20 lbs. at a moderate velocity. The merchants and wharfingers would inſtantly diſcharge from their ſervice any porter who would refuſe to carry a load of more than 20 lbs., yet theſe very merchants and wharfingers are daily paying full wages to cranemen for exerting a force which, when duly applied, is greatly within the power of a boy of 10 or 12 years of age. And as to the common walking-wheel, the men who are ſtationed within it expend a great portion of their ſtrength in moving themſelves *forward;* which proves unproductive, becauſe the effective velocity is only according to the ſum of the heights attained, and the waſte of force through ſuch unprofitable deviation from the vertical direction renders the men incapable of the due velocity of aſcent: beſides, the velocity of deſcent, which ought to be proportional to a due velocity of aſcent, is materially impaired by ſhortening of the effective lever in the courſe of its depreſſion, and a conſequent diminution of mechanical power; and theſe obſtructions are frequently aggravated, by placing men in the wheel to walk behind the others. And when this loſs of labour by the often counter-operation of a rear rank is avoided by applying an additional wheel, the machine occupies much ſpace, becomes extremely expenſive, and is attended with extraordinary friction. Although nothing but neceſſity can juſtify the hazarding of the lives of men, yet the walking-wheel is attended with imminent danger; and being a very defective engine, employed without either neceſſity or expediency, thoſe perſons who uſe them are reſponſible to humanity for the ſhocking diſaſters they frequently occaſion. But the various evils juſt enumerated, as well as many others which attend the cranes now adverted to, have been obviated in a very effectual manner by Mr. Hardie; whoſe crane is at once ſo ſimple and efficient, as to render it no eaſy taſk to point out any faults which it has not avoided, or any defects which it has not ſupplied. It is a walking-crane; but the men walk on the outſide of the wheel, inſtead of inſide of the rim; and during the whole of their labour they are expoſed to no kind of danger, and they can walk in an upright poſture, well ſuited to free reſpiration. Five cranes of the kind are at work at the Eaſt-India warehouſes: and as the contrivance (for which Mr. Hardie has obtained a patent) muſt ultimately prove a conſiderable acquiſition, we have examined the conſtruction and mode of operation of two of theſe machines with particular attention, that we might be enabled to furniſh the public with the following deſcription.

The reader may turn to plate XI. where fig. 1. is an elevation of the ſide of the crane on which the men operate.

Fig. 2. An elevation of the end of the ſtage to aſſiſt the men in ſtepping on and off the wheel, as well as to ſupport a ſeat for them to reſt upon, in the intervals between the operations. The edge *f* of this ſtage does not ſtand more than 4 inches from the point *s* by which the edge of each ſtep paſſes.

Fig. 3. An elevation of the end of the wheel.

Fig. 4. An elevation of the ſide of the crane, oppoſite to that given in fig. 1. The ſame letters of reference being put to the correſponding parts in theſe figures.

AA is a wheel (on the principle of the wheel uſed in China for men working at the chain-pump, for raiſing water to the higher grounds, employed in the culture of rice), on the outſide of which are placed 24 ſteps for the men to tread upon, at a ſituation where the ſteps are found at a height equal to that of the axis, or where the plane of the ſteps become horizontal; the diameter of the wheel being 6 feet, ſteps included. The crane repreſented in the figure is adapted for 4 men; though they may eaſily be contrived for 5, 6, or 8. At one end is B, the crane rope barrel, of a diameter ſuited to the drafts of goods commonly raiſed, and the number of men generally allowed, with C a brake-wheel, all fixed on the ſame axis, and D a brake attached to the framing of the crane, to preſs on the brake-wheel, occaſionally to ſtop or retard the motion; being conducted by a man at the loop-hole by means of E, a lever of wood, loaded with a piece of lead or caſt-iron at the extremity, to give it ſufficient weight to ſtop the motion of the wheel; a rope faſtened to the end of this lever, and conveyed over two pulleys, terminates in a handle for the loop-hole man, with an iron ring at the lower part thereof to receive a pig, fixed at the ſide of the loop-hole for the purpoſe of keeping it down, that the lever might diſengage the brake from the brake-wheel during the operation of raiſing the goods. G, G, G, G, G, are vertical handles, and H, H, H, H, H, horizontal handles for the men to take hold of with both hands, when treading on the ſteps: ſometimes both hands are applied to the vertical handles; at others, one hand to a vertical, and the other to a horizontal handle; and at others, both hands to the horizontal handles; thus producing a variety in the action, and, when neceſſary, a conſiderable augmentation to the force. I (fig. 1. and 3.) is a pawl which drops in at every ſtep, to prevent the wheel and its incumbent weight from overpowering the men at any time: it has at its lower part a cord with a loop to paſs over one of the horizontal handles, near the extremity of which there is a notch ſufficiently deep to retain the loop when drawn into it, for the purpoſe of raiſing the pawl, to diſengage it from the wheel preparatory to the operation of lowering the goods or crane-rope.

Now it is obvious, that by treading on the ſteps as they arrive at the poſition *t*, *t* (figs. 1. 3.), juſt above the horizontal plane, paſſing through the axis, the men both aſcend and deſcend nearly in the vertical direction: of conſequence, the greateſt poſſible velocity is produced without any unproductive labour; and the men are enabled to maintain the action by means of a hold of an upright handle on each hand; or occaſionally to augment the action, by puſhing at theſe handles. Further, by taking hold of the horizontal handles, each man can, by an act ſimilar to that of lifting, augment the force ariſing from his weight through all the degrees, from about 150 to 300 lbs. So that the ſame number of men can perform many operations of raiſing greater drafts than uſual; ſuch as with the common walking-wheel or moſt other cranes could not be accompliſhed without additional men: and the pawl which drops in each ſtop provides in the moſt effectual manner for the ſafety of the men, even if the crane had not been ſo conſtructed that their feet need never be more than 12 inches diſtant from the ſtage S*f*, and the diſtance *fs* far too ſmall to admit of falling through. Thus the very judiciouſly choſen dimenſion of a 6-feet diameter unites the advantages of a weight acting on a horizontal inſtead of inclined lever with thoſe accruing from the vertical and horizontal handles; while it completely precludes the danger which attends the common walking-wheel, and has by no means ſo much friction as neceſſarily attends Mr. Whyte's crane.

Mr. Hardie has likewiſe contrived a truly advantageous mode of operating without a gibbet, which he has carried into effect with four of his cranes. He has placed the crane at the top of the warehouſe, ſo as to allow the crane-rope to drop directly down from the barrel of the crane in front of the loop-holes; and at the upper floors, where the ſhortneſs of the rope diminiſhes the ſwing of the goods in or out of the loop-holes, he has provided a ſliding floor immediately under the floor of the warehouſe, which one man draws out or in, by pulling a cord, with the greateſt eaſe, to receive or deliver the goods by a truck at the loop-hole. The part of the warehouſe floor which is immediately above the ſliding floor conſiſts of a thin plate of caſt iron, which allows the truck to run off the one on the other without any obſtruction. Thus more than one man's labour in five or ſix is ſaved, by getting rid of the friction of the pulley of a gibbet; and a ſtill greater ſaving of labour is effected by accelerating all the movements at the loop-holes.

9. The common method of lowering goods by the brake and brake-wheel, even with the aſſiſtance of a counter-weight, is liable to injurious accidents to the men, as well as to the goods, when they conſiſt of periſhable articles, ſuch as wine, ſpirits, glaſs, &c. Sometimes, from the rapid motion of the crane, parts of it fly off with violence, and kill or wound the perſons near it: at other times the brake-rope becomes entangled by turning off the pulleys or otherwiſe, or the rope ſlips out of the hand of the man who conducts it: in either of which caſes the goods might deſcend with all the accelerated velocity of a falling body, receiving damage, and killing or maiming the men, horſes, &c. which happen to be under them. But theſe evils are completely remedied by a *lowering regulator* of the following deſcription, invented by Mr. Hardie.

Pl. XI. fig. 5. A ſection of the regulator.

Fig. 6. An elevation of one end of the regulator. The ſame letters of reference being put to the correſponding parts in theſe figures.

AA, a caſt-iron box fixed to the floor B, divided into two compartments, each 10 inches long, one of 4 inches diameter, and the other of 2 inches diameter: theſe are both filled with oil, a liquid not ſubject to any material change by froſt; or they may be filled with water in ſummer and mild weather, and ſome ſpirituous liquor (gin, for inſtance) in froſty weather. The two cylinders communicate with each other by C, an aperture at their top, and D, an aperture at their bottom; the ſmaller compartment having a cock E, with its axle paſſing through the ſide of the iron box, guarded by a ſtuffing-box, and G a quadrant with notches fixed at its end, to receive H the iron claw, which keeps the cock in its proper ſituation, and ſhews the extent of its apertures when opened. The larger compartment has a piſton F, with its rod paſſing through I, the top of the iron box (guarded here alſo by a ſtuffing-box), and paſſing through a guide: this rod is connected with a joint moved by a crank, which is turned by a pinion P of about 6 teeth; and this pinion is moved by a wheel, of a ſize ſuited to the diameter of the barrel of the crane and the weight of the goods commonly lowered: this latter wheel is fixed to the axle of the crane by a ſimple mode of connection, which admits of its being diſengaged during the operation of riſing; it is alſo provided with the barrel rope and counter-weight, which are commonly uſed for the purpoſe of winding up the ſlack crane rope on the barrel of the crane, to be ready to repeat the operation of lowering.

If the cock E were quite ſhut, the oil or other liquid confined between it and the piſton would prevent the piſton from moving, and of courſe hinder the goods hanging from the wheel, &c. connected with P from deſcending: but if the cock were opened a very little the oil would paſs ſlowly through it, and would therefore allow the piſton F to move up and down ſlowly, and the goods to deſcend ſlowly alſo: and, in like manner, a further opening of the cock will permit the load to deſcend with a greater velocity: thus the cock, by being more or leſs opened, gives the preciſe velocity deſired to the deſcent of the goods, whatever their weight may be.

When a ſmall pinion turned by a winch is applied to the tooth-wheel, occaſionally employed to turn the pinion of the crank, one man with eaſe raiſes the goods an inch or two, in order to be ſwung from the floor preparatory to lowering; the natural defect of the winch as a raiſing inſtrument being of no conſideration in ſuch caſe, where the goods are raiſed merely to clear the floor: ſo that this crane and lowering apparatus poſſeſſes a much higher degree of perfection in lowering than any of the other cranes. The means afforded of regulating it to lower either ſmall or great weights with facility, expedition, and ſafety, and without depending, during the operation, on the precarious attention and management of a man, render it, in our opinion, far preferable to the hazardous and limited mode of lowering goods by the brake: while, with reſpect both to ſafety and great ſaving of labour, it obviouſly ſurpaſſes the modes of lowering by the capſtan and the walking-wheel, which require nearly the ſame number of men to lower that they take to raiſe any weight.

We have dwelt the longer upon the ſubject of cranes, becauſe it is manifeſtly of the firſt importance in a commercial nation: ſomething further, of too much utility to be entirely omitted, may perhaps be found under the articles ENGINE *to let down weights*, GIBBET, and LOADING *and unloading of goods*.

CRANE is alſo a popular name for a ſyphon employed in drawing off liquors.

This crane or ſyphon is nothing elſe than a bent tube, as ABG (fig. 5. pl. X.). If the ſhorter end AB be immerſed in a veſſel of water or other fluid C, then by applying the mouth to the end G, and ſucking till the liquor arrives there, it will continue to flow out at the end G, as long as that end is lower than the ſurface of the fluid in the veſſel C. If there be a mouth-piece at E, then ſucking at that mouth-piece (while the end G is ſtopt with a finger or otherwiſe) will make the fluid flow when the obſtruction is taken away from G. When the fluid has begun to flow, the hole at E muſt be ſtopped up, or the fluid will flow no longer than till the ſurface in the veſſel be as low as E.

The reaſon of the motion of the liquor in the ſyphon is this: the perpendicular height of the column BG being greater than that of BA, the preſſure at G is greater than at A; and the preſſure of the atmoſphere being the ſame at both orifices (ſuppoſing them of equal area), therefore the weight at G will cauſe the fluid to flow out there, while the preſſure of the atmoſphere will force more liquor up the end A; and thus the motion will continue ſo long as there is any fluid in the veſſel, provided the end G is lower than the end A of the ſyphon. Hence it is manifeſt that the height from the ſurface of the fluid in the veſſel to the top B of the ſyphon muſt not exceed the altitude of a column of the fluid whoſe weight is equal to the preſſure of the atmoſphere on the ſame baſe.

The operation of ſucking out the liquor at G, which is often both diſagreeable and troubleſome, may be prevented by having an aperture at the top B, through which the ſyphon may be completely filled, and then that aperture cloſed again. Or a ſmall ſyphon may be inverted, and filled with the fluid, which may be kept in by a finger applied at each end until it is placed in the proper poſition for work, when the fingers may be removed.

The ſyphon will raiſe a ſtream of water through an extenſive ſpace in every ſituation where a little deſcent can be procured; but while the operation continues no water can be taken directly out of the ſtream above the loweſt part of the tube. When, however, the two open ends of a ſyphon are cloſed, a quantity of water may be let out of the higheſt part, and its place ſupplied by introducing a like quantity which is of no other uſe: all the avenues for the purpoſe being then cloſed, and the ſtream ſuffered to flow through the tube, the uſeleſs water will be diſplaced, and a freſh quantity may be ſoon after drawn off. This mode of exchange may be uſeful in furniſhing a ſupply for waſhing, and ſome other purpoſes; but there are ſeveral domeſtic uſes for which the water drawn off will not be thought ſufficiently pure. A method of taking water out of the ſyphon at any height within the limits of the elevation, without retarding the ſtream or introducing another quantity, has long been thought very deſirable. Mr. *William Cloſe*, of Dalton, made a number of experiments and obſervations to determine the practicability of the project; from which he at length deduced the following arrangement for extracting a quantity of *water* out of a ſyphon at any elevation (within its limits), and ſupplying its place with *air*.

Into any part except the top ſide of a vertical ſyphon SY (fig. 5. pl. X.) inſert two ſmall pipes, and let their apertures in the inſide of the tube be divided by a projecting piece about a quarter of an inch thick; wherever the pipes are inſerted, the piece muſt be placed in ſuch a poſition that the current will ſtrike againſt one of its flat ſides. The pipe which opens on that ſide of the obſtacle or dam ſtruck by the ſtream may be called the *water-pipe*, and that on the other ſide the *air-pipe*. Inſert their other ends into a veſſel *a w*. The air-pipe oppoſite to *a* muſt riſe to near the top of this veſſel, but the water-pipe *w* need not ariſe above the place of its inſertion. A cock, perfectly air-tight, muſt be fixed in each pipe between the veſſel and ſyphon: the veſſel *a w* muſt have a tube *t* in its lower part, for letting out water; and this tube muſt have a cock fixed in it, or a valve covered with leather to cloſe its lower end. To haſten the delivery of the water in this veſſel, the external air may be admitted, in ſuch manner as is moſt convenient.

The communication between the veſſel and ſyphon being intercepted by turning the cocks in the pipes *a w*, and the branches of the ſyphon cloſed at their lower ends, the tube may be filled with water through an aperture in the top. After this aperture is cloſed, and a ſtream of water let into the ciſtern C for ſupplying the ſyphon, the ends of the branches may be opened, and a continued ſtream will flow through the tube.

When it is required to fill the veſſel *a w* with water, exclude the external air, and open the pipes between it and the ſyphon.

The veſſel will ſoon be filled, and the water may be let out by opening the tube *t*, after the ſmall pipes *a w* are again cloſed by turning their cocks.

The water may be let out of the veſſel without attendance, by a quantity of water paſſing through four veſſels placed in the following order one below another, and each provided with a ſyphon.

1. The higheſt, an immoveable veſſel filled in a given time. 2. A deſcending veſſel, ſuſpended from a lever or a wheel, which turns the cocks in the tubes oppoſite *a w* in its axis. This veſſel muſt have a tube open at both ends, fixed in the middle of its bottom. 3. A deſcending veſſel, to open the valve for letting water out of the veſſel *a w*. It muſt be ſuſpended upon the valve by a cord or wire paſſing through the tube, in the middle of the ſecond veſſel. 4. The loweſt, a veſſel of the ſame width with the ſecond. The brim of it muſt be connected to the outſide circumference of the bottom of the ſecond, by wires or chains.

In this arrangement the firſt veſſel will empty itſelf into the ſecond, which will cloſe the cocks in the pipes oppoſite *a* and *w*, before air is admitted into the veſſel *a w*. The third will be filled from the ſecond, and the water in the veſſel *a w* will be let out again; the third will deliver its contents into the fourth or loweſt, which will keep the cocks in the ſmall pipes oppoſite *a* and *w* cloſe, until after the third veſſel is empty, has riſen up, and the external air can no longer enter the veſſel *a w*. The fourth being then emptied by its ſyphon, the pipes between the veſſel *a w* and ſyphon SY will open.

The diameter of the ſecond veſſel ſhould be ſomething leſs than either that above or below it. The fourth ſhould be filled before the ſecond is empty: the third will deſcend laſt, and riſe firſt: the ſecond and fourth will riſe together, immediately after the third. If the ſecond and fourth were to riſe before the third the ſyphon would directly receive a quantity of external air, and its operations would ceaſe. It will, therefore, require much caution to manage the cocks and valves, if another veſſel ſimilar to *a w* is to be filled while this laſt is emptied, and emptied while it is filled.

The veſſel *a w* ſhould not be large; and, in order to overcome the buoyance of the extracted air, it is adviſable to make the length of the deſcending branch of the ſyphon exceed the length of the aſcending one as much as circumſtances will admit, and to let the loweſt part of it be made of a conical divergent form. The velocity of the ſtream will be thus encreaſed; the veſſel *a w* will be ſooner filled with water; and the depreſſion of the two columns will be leſs liable to happen from very ſlight imperfections of workmanſhip. *Nicholſon's Journal,* 4to, vol. IV. p. 550.

Mr. Cloſe made many ſubſequent trials, to bring this apparatus to the greateſt perfection it would admit of: the reſult of the whole may be ſeen in No. 45. of the New Series of Nicholſon's Journal, where Mr. Cloſe has given the deſcription and effects of an apparatus for raiſing water by means of air condenſed in its deſcent through an inverted ſyphon.

CYLINDERS *for* STEAM ENGINES, *boring of,* is an operation uſually carried on at the foundery where they are caſt. Though the moulder purſues the moſt correct method his art is capable of, yet it is impoſſible to be certain that when the mould has received the metal from the furnace it ſhall come out quite ſtraight; and if it ſhould come out crooked it muſt remain ſo; for the old method of boring will never make it otherwiſe in that reſpect. It is not like boring a piece of metal which is quite ſolid, as in boring guns, &c. All the old boring can do to a cylinder is to make it round and ſmooth, for there is nothing to conduct the boring bit in its progreſs through the piece but the form given it by the moulder; and a piece bored after this manner may look very well, yet if it is not ſtraight it is not a cylinder: and an engine executed with ſuch a veſſel as that will be good or ill in that reſpect, as it approaches to or is further off the degree of exactneſs conſtituting it a cylinder.

The new method of boring (which, as is obſerved, article STEAM ENGINE, was firſt practiſed at Burham, a foundery belonging to Mr. Wilkinſon, iron-maſter) inſures all the perfection the ſubject is capable of; and when the proceſs is conducted by an intelligent workman, if the cylinder ſhould be caſt ever ſo crooked, or ever ſo thick on one ſide more than another, he can take out the redundancy on that ſide, and but ſcarcely touch the other. This will be eaſily admitted when it is underſtood that, whereas in the old method of boring the inſtrument which performs the part of cutting the metal is guided in its progreſs by the already incorrect form of the piece itſelf; but in the new method the cutting apparatus is conducted along a thing which in itſelf is a maſterpiece of workmanſhip, a perfect cylinder, and is what the workmen call *the boring bar,* and is caſt of the beſt pigs that can be procured, and turned with the utmoſt care and preciſion: conſequently, whatever is conducted along this bar will proceed in a right line; and as it is intended that this ſhall be the conductor of the cutter-block, being furniſhed with proper cutters, it muſt cut the interior ſurface of the piece quite ſtraight, though it may have been ever ſo crooked before.

Then this bar being turned very true, it is to have a groove or, two cut oppoſite to each other, in a line parallel to its axis; then there is a ſocket of caſt iron of ſuch dimenſions as to ſuit for cylinders of various diameters, and this ſocket is to be nicely bored and ground on the bar; and then it muſt have a fillet or two (according to the groove or grooves in the bar) let in on the inſide, ſo as to ſlide along the bar, but not to turn round upon it: the external part muſt be made conical, with four or ſix ſtuds upon the baſe of it to receive the cutter block. The next thing is to give a progreſſive motion to this ſocket and cutter block while the bar is turning on its own axis; and that is done by ſome with a collar of metal fitted on the ſocket, and to that collar are connected two racks, long enough to reach through the cylinder and communicate with a pair of pinions, by which the ſocket is drawn or puſhed along the boring bar by the means of two levers, carrying a weight at each ſufficiently heavy to overcome all reſiſtance in the operation.

Another method of giving a progreſſive motion to the block is to drill a hole through the whole length of the bar, to admit a ſingle rod, to be communicated to the ſocket by ſinking *the groove* (for in this caſe there can be but one) entirely through one ſide of the bar, ſo as to come into the hole that has juſt been drilled through the bar. Then a branch from the internal part of the ſocket muſt be fitted into the groove with an eye to receive the end of the rod, which is then to be furniſhed with a key, or a nut and waſher, to keep it in its place while the bar and ſocket is turning round, and a weight with a rope over a pulley is applied to give motion to the ſocket along the bar. This is the beſt way of applying this method to boring of ſmall cylinders, becauſe there is no incumbrance upon the ſocket; and if the bar is ſufficiently ſtrong it will move with great ſteadineſs.

ELLIPSOGRAPH is the name given by the anonymous author of a German publication, entitled "*Beſchreibung eines Ellipſograph, womit man wahre Ellipsen ohne Berechnung der Brennpunkte ſehr leicht beſchreiben kann*, &c. publiſhed at Gotha in 1794, to a ſimple and univerſal inſtrument for drawing ellipſes. The inſtrument has been long known to our mathematicians, and has been deſcribed, though not in ſuch general terms as it admits of, in Emerſon's Conics, Hutton's Mathematical Dictionary, and other works; but as it has not yet been adopted for practical purpoſes, though it is far preferable, in our opinion, to any inſtrument for drawing ellipſes now in uſe, we take this opportunity of recommending it to general notice.

The ellipſograph conſiſts of three flat and moderately thin rulers of wood or braſs, two of which muſt be of equal lengths; and it may be as well if the length of theſe two together be equal to that of the third ruler. Let the two ſhorter of theſe rulers be pierced with a number of holes at equal diſtances, the holes being capable of receiving either a pin on which the rulers may turn as upon a joint, or a pencil by which the curve may be deſcribed: then by connecting theſe rulers either as in fig. 5. or fig. 6. pl. XIV. an ellipſe may be readily deſcribed. Thus, in fig. 5. hang one end of the ruler AB upon a pin in the middle of the ruler KL, and take the point B ſuch that AB = BD, and AB + BD = ſemiconjugate + ſemitranſverſe of the ellipſe, the ruler BD turning upon a pin in B as a joint: take the point E ſo that DE = ſemiconjugate, and put a pencil into the hole of that point: then, if the end D of the ruler BD be ſlidden along the edge KL of the ruler which paſſes through the centre A, the pencil at E will deſcribe a true ellipſe having the propoſed diameters. Again, taking the method repreſented in fig. 6. upon the ruler AC, hang the ruler BG at B, ſo that AB + BE = ſemitranſverſe, while AB = BD = half the difference of the ſemitranſverſe and ſemiconjugate axes: then, while a pin at D ſlides along the edge of the ruler KL the pencil at E will deſcribe the ellipſe required. The truth of this method of conſtruction is demonſtrated in Emerſon's Conics, prop. 75. ellipse.

This inſtrument may, it is obvious, be eaſily made either ſo as to conſtruct ſmall ellipſes, now commonly deſcribed by means of the elliptical compaſſes; or upon a larger ſcale, for the purpoſe of deſcribing elliptical centring for arches of bridges, &c. In the latter caſe the ellipſograph may be made ſufficiently ſtrong without being any way cumberſome in practice. In the actual conſtruction of the inſtrument the ruler KL ſhould be the thickeſt, and the other two legs made to run upon friction rollers, as in the conſtruction of the pentagraph.

It may not be altogether uſeleſs juſt to remark, that in both methods of uſing the inſtrument the point B will deſcribe a circular arc; and if the ruler DB had a part *above* B, equal to DB, the upper extremity of that part would, during the motion of the point D along KL, deſcribe a right line. This follows evidently from what was ſhewn in art. 8. of the introductory part of this volume.

ENGINE *to let down heavy weights.* The ſimple method we are now about to deſcribe was invented by father *Reſſin*, in 1714. Suppoſe it were required to lower large ſtones from the top of a wall which is intended to be taken down: erect a frame, or ſet up a gin cloſe by the ſide of the wall, and let the pulley P (fig. 4. pl. IV.) be firmly attached to this frame. Over this pulley muſt paſs a cord, one end of which C has a hook to which the ſtone, &c. can readily be faſtened; the other end D carries a veſſel, which may be filled with water from the reſervoir M, on the ground at the bottom of the wall. Then, while one man is fixing the ſtone to the hook at the top of the wall, let another put water into the veſſel D at the bottom till it nearly equals the weight of the ſtone: after which, leaving both to the free operation of gravity, or checking the motion a little if neceſſary, the ſtone will gradually deſcend to the ground, while the veſſel D will be carried up to a funnel A, into which the water may be poured, and thence conveyed by a wooden or a leather pipe to the reſervoir M. Then the veſſel D may be ſuffered to deſcend, and the hook C will be raiſed to be fixed to another ſtone: and thus the operation may be repeated as often as is neceſſary.

The ſame method may likewiſe be adopted in lowering ſacks from a high granary, or packages from an upper warehouſe. The velocity of the deſcending weight may be ſo regulated as to have any proportion to that which gravity imparts to bodies falling freely: thus, if W denote the weight to be lowered, V that of the veſſel of water, we ſhall have $\frac{W-V}{W+V}$, for the fraction expreſſing the ratio of the velocity to that freely imparted by gravity when denoted by unity. Thus, if $V=\frac{1}{2}W$, the weight will fall through $\frac{1}{3}$ of $16\frac{1}{12}$, or about $5\frac{1}{3}$ feet in the firſt ſecond: if $V=\frac{2}{3}W$, the weight will fall through $\frac{1}{5}$ of $16\frac{1}{12}$, or about $3\frac{1}{5}$ feet in the firſt ſecond: the friction of the pulley being in both inſtances diſregarded.

FILES, *machine for cutting of.* There have been various contrivances for this purpoſe; but the beſt we are acquainted with is deſcribed in the Tranſactions of the American Philoſophical Society, and is as follows: AAAA fig. 6. pl. X. is a bench made of well-ſeaſoned oak, the face of which is planed very ſmooth. BBBBB the feet of the bench, which ſhould be ſubſtantial. CCCC the carriage on which the files are laid, which moves along the face of the bench AAAA parallel to its ſides, and carries the files gradually under the edge of the cutter or chiſel HH, while the teeth are cut: this carriage is made to move by a contrivance ſomewhat ſimilar to that which carries the log againſt the ſaw of a ſaw-mill, as will be more particularly deſcribed. DDD are three iron rods, inſerted into the ends of the carriage CCCC, and paſſing through holes in the ſtuds EEE, which are ſcrewed firmly againſt the ends of the bench AAAA, for directing the courſe of the carriage CCCC, parallel to the ſides of the ſaid bench. FF two upright pillars, mortiſed firmly into the bench AAAA nearly equidiſtant from each end of it, near the edge, and directly oppoſite to each other. G the lever or arm which carries the cutter HH (fixed by the ſcrew I), and works on the centres of two ſcrews KK, which are fixed into the two pillars FF in a direction right acroſs the bench AAAA. By tightening or looſening theſe ſcrews the arm which carries the chiſel may be made to work more or leſs ſteadily. L is the regulating ſcrew, by means of which the files may be made coarſer or finer; this ſcrew works in a ſtud M which is ſcrewed firmly upon the top of the ſtud F: the lower end of the ſcrew L bears againſt the upper part of the arm G, and limits the height to which it can riſe. N is a ſteel ſpring, one end of which is ſcrewed to the other pillar F, and the other end preſſes againſt the pillar O, which is fixed upon the arm G; by its preſſure it forces the ſaid arm upwards, until it meets with the regulating ſcrew L. P is an arm with a claw at one end marked 6, the other end is fixed by a joint into the end of the ſtud or pillar O; and, by the motion of the arm G, is made to move the ratch-wheel Q. This ratch-wheel is fixed upon an axis, which carries a ſmall trundle-head or pinion R, on the oppoſite end; this takes into a piece SS, which is indented with teeth, and ſcrewed firmly againſt one ſide of the carriage CCCC: by means of this piece motion is communicated to the carriage. T is a clamp for faſtening one end of the file ZZ in the place or bed on which it is to be cut. V is another clamp or dog, at the oppoſite end, which works by a joint W, firmly fixed into the carriage CCCC. Y is a bridge, likewiſe ſcrewed into the carriage, through which the ſcrew X paſſes, and preſſes with its lower end againſt the upper ſide of the clamp V; under which clamp the other end of the file ZZ is placed, and held firmly in its ſituation while it is cutting, by the preſſure of the ſaid clamp V. 7777 is a bed of lead, which is let into a cavity formed in the body of the carriage, ſomething broader and longer than the largeſt ſized files; the upper face of this bed of lead is formed variouſly, ſo as to fit the different kinds of files which may be required. At the figures 2 2 are two catches which take into the teeth of the ratch-wheel Q, to prevent a recoil of its motion. 3 3 is a bridge to ſupport one end 4 of the axis of the ratch-wheel Q, 5 a ſtud to ſupport the other end of the axis of that wheel.

When the file or files are laid in their place, the machine muſt be regulated to cut them of the due degree of fineneſs, by means of the regulating ſcrew L; which, by ſcrewing further through the arm M, will make the files finer, and, *vice verſa*, by unſcrewing it a little, will make them coarſer; for the arm G will, by that means, have liberty to riſe the higher, which will occaſion the arm P, with the claw, to move further along the periphery of the ratch-wheel, and conſequently communicate a more extenſive motion to the carriage CCCC, and make the files coarſer.

When the machine is thus adjuſted, a blind man may cut a file with more exactneſs than can be done in the uſual method with the keeneſt ſight: for by ſtriking with a hammer on the head of the cutter or chiſel HH, all the movements are ſet at work; and, by repeating the ſtroke with the hammer, the files on one ſide will at length be cut: then they muſt be turned, and the operation repeated, for cutting the other ſide. It is needleſs to enlarge much on the utility or extent of this machine; for, on an examination, it will appear to perſons of but indifferent mechanical ſkill, that it may be made to work by water as readily as by hand, to cut coarſe or fine, large or ſmall, files, or any number at a time; but it may be more particularly uſeful for cutting very fine ſmall files for watchmakers; as they may be executed by this machine with the greateſt equality and nicety imaginable. As to the materials and dimenſions of the ſeveral parts of this machine, they are left to the judgment and ſkill of the artiſt who may have occaſion to make one; only obſerving that the whole ſhould be capable of bearing a good deal of violence.

FIRE-ESCAPE, a machine for removing perſons from the upper ſtories of houſes on fire. It conſiſts of a pole, a rope, and a baſket. The pole is of fir, or a common ſcaffold pole, of any convenient length from 36 to 46 feet. The diameter at bottom, or greateſt end, about five inches; and at the top, or ſmalleſt end, about three inches. At three feet from the top is a mortiſe through the pole, and a pulley fixed to it of nearly the ſame diameter with the pole in that part. The rope is about three quarters of an inch diameter, and twice the length of the pole, with a ſpring hook at one end, to paſs through the ring in the handle of the baſket when uſed: it is put through the mortiſe over the pulley, and then drawn tight on each ſide to near the bottom of the pole, and made faſt there till wanted. The baſket ſhould be of ſtrong wicker-work, three feet and a half long, two feet and a half wide, rounded off at the corners, and four feet deep, rounding every way at the bottom. To the top of the baſket is fixed a ſtrong iron curve or handle, with an eye or ring in the middle; and to one ſide of the baſket, near the top, is fixed a ſmall cord, or guide-rope, of about the length of the pole. When the pole is raiſed, and ſet againſt a houſe over the window from which any perſons are to eſcape, the manner of uſing it is ſo plain and obvious, that it need not be deſcribed. The moſt convenient diſtance from the houſe for the foot of the pole to ſtand, where practicable, is about 12 or 14 feet. If two ſtrong iron ſtraps, about three feet long, riveted to a bit croſs, and ſpreading about 14 inches at the foot, were fixed at the bottom of the pole, this would prevent its turning round or ſlipping on the pavement: and if a ſtrong iron hoop, or ferrule, riveted (or welded) to a ſemicircular piece of iron ſpreading about 12 inches, and pointed at the ends, were fixed on at the top of the pole, it would prevent its ſliding againſt the wall.

When theſe two laſt-mentioned irons are fixed on, they give the pole all the ſteadineſs of a ladder; and becauſe it is not eaſy, except to perſons who have been uſed to it, to raiſe and ſet upright a pole of 40 feet or more in length, it will be convenient to have two ſmall poles or ſpars of about two inches diameter, fixed to the ſides of the great pole at about two or three feet above the middle of it, by iron eyes riveted to two plates, ſo as to turn every way; the lower end of theſe ſpars to reach within a foot of the bottom of the great pole, and to have ferules and ſhort ſpikes to prevent ſliding on the pavement, when uſed occaſionally to ſupport the great pole like a tripod. There ſhould be two ſtrong aſh trundles let through the pole, one at four feet and one at five feet from the bottom, to ſtand out about eight inches on each ſide, and to ſerve as handles, or to twiſt the rope round in lowering a very heavy weight. If a block and pulley were fixed at about the middle of the rope, above the other pulley, and the other part of the rope made to run double, it would diminiſh any weight in the baſket nearly one-half, and be very uſeful in drawing any perſon up to the aſſiſtance of thoſe in the chambers, or for removing any effects out of a chamber, which it might be dangerous to attempt by the ſtairs.

It has been proved, by repeated trials, that ſuch a pole as we have been ſpeaking of can be raiſed from the ground, and two or three perſons taken out of the upper windows of a houſe, and ſet down ſafely in the ſtreet, in the ſpace of 35 ſeconds, or a little more than half a minute. Sick and infirm perſons, women, children, and many others, who cannot make uſe of a ladder, may be ſafely and eaſily brought down from any of the windows of a houſe on fire by this machine, and, by putting a ſhort pole through the handles of the baſket, may be removed to any diſtance without being taken out of the baſket. The pole muſt always have the rope ready fixed to it, and may be conveniently laid up upon two or three iron hooks under any ſhade or gateway, and the baſket ſhould be kept at the watch-houſe. When the pole is laid up, the two ſpars ſhould always be turned towards the head of it. The baſket ſhould be made of peeled rods, and the pole and ſpars painted of a light ſtone-colour, to render it more viſible when uſed in the night.

FIRE-ENGINE, the name now commonly given to a machine by which water is thrown upon fires in order to extinguiſh them. Various machines have been contrived for that purpoſe at different times; the moſt eſſential particulars in a few of which we ſhall here deſcribe.

The uſual conſtruction of the fire-engine, after the great improvements were made in it by Mr. R. Newſham, was nearly that which is exhibited in fig. 2. pl. XV. where we have repreſented a vertical ſection of the engine. The motion of the water in this machine is effected by the preſſure of the atmoſphere, the force of men acting upon the extremities H', H'', of a lever, and thence giving motion to the piſtons, and by the elaſticity of condenſed air, in the following manner:—When the piſton R is raiſed a vacuum would be made in the barrel TU if the water did not follow it from the inferior canal EM (through the valve H), which riſes through the tube EF immerſed in the water of a veſſel by the preſſure of the atmoſphere on its ſurface. The water of the barrel TU, by the ſucceeding depreſſion of the piſton R, ſhuts the valve H, and is forced, through the ſuperior canal ON, to enter by the valve I into the air-veſſel *a b c d*; and the like being done alternately with reſpect to the other barrel WX, and its piſton S, the air-veſſel is, by theſe means, continually filling with water, which greatly compreſſes the air above the ſurface of the water in that veſſel, and thereby proportionally augments its ſpring; which at length is ſo far increaſed as to re-act with great force on the ſurface YZ of the ſubjacent water, and compel it to aſcend through the ſmall tube *e f* to the ſtop-cock *e g*, where upon turning the cock the water is ſuffered to paſs through a pipe *h* fixed to a ball and ſocket; from the orifice of which it iſſues in a continued ſtream with a great velocity, to a conſiderable height or diſtance; and it is uſually kept from diverging too ſoon in its progreſs by means of a long ſeries of flexible leather pipes, properly joined together, and known among the fire men by the name of the hoſe.

Deſaguliers remarks (vol. I. p. 257.) that Mr. Newſham contrived his engines in ſuch a manner, "that part of the men who work them exert their force by treading, which is more effectual than any other way that men can work at ſuch engines; the whole weight of the body being ſucceſſively thrown on the forcers of the pumps: and even part of a man's ſtrength may be added to the weight by means of horizontal pieces to which he can apply his hands when he is treading: whereas, by applying the hands to move levers or turn winches, the power muſt act very unequally. This is the reaſon why with the ſame number of men he has generally thrown water further, higher, and in greater quantities, with the ſame ſized engines, than other engineers who have tried their engines againſt his." Notwithſtanding the truth of this remark, we are not aware that the combination of human weight and ſtrength here recommended has been practiſed in any ſubſequent fire-engines, or indeed in any machines whatever, except the ingenious walking crane of Mr. Hardie.

The greateſt artifice in the engine according to the conſtruction juſt deſcribed is the contrivance to produce a *continual ſtream*, which is done by the compreſſion and proportional elaſticity of air in the barrel *a b c d*, called the air-veſſel. For the air, being an elaſtic fluid, will be ſuſceptible of compreſſion in any degree by the water forced in through the valves at IK; and, ſince the force of the air's ſpring will always be inverſely as the ſpace it poſſeſſes (art. 489. vol. I.), it follows that when the air-veſſel is half full of water the air will be compreſſed into half the ſpace it poſſeſſed at firſt, and therefore its ſpring will be twice as great as at firſt.

But this ſpring at firſt was equal to the preſſure of the atmoſphere on the ſame ſurface: for if it were not it could not have ſuſtained or reſiſted the preſſure of the atmoſphere which ſtood over it, and conſequently could not have filled the veſſel before the water was driven in; which yet we find it did, and maintained an equilibrium with the common air. The veſſel then being half filled with water, or the air compreſſed into half the firſt ſpace, its ſpring will in this caſe be equal to twice the preſſure of the atmoſphere; and therefore when the ſtopcock at *p* is turned, the air within, preſſing on the ſubjacent water with twice the force it meets with from the external air in the pipe *e f*, will cauſe the water to ſpout out of the engine to the height of 32 or 33 feet, if the friction is not too great.

When the air-veſſel is $\frac{2}{3}$ full of water, the air takes up $\frac{1}{3}$ part; whence its ſpring will be three times as great as that of the common air, and it will project the water with twice the common atmoſpheric preſſure; conſequently, it will riſe to the height of 62 or 64 feet. When the air-veſſel is $\frac{3}{4}$ full of water the air will be compreſſed into its $\frac{1}{4}$ part, and ſo will protrude the water with three times the atmoſpheric preſſure, and carry it to the height of 96 or 99 feet. Hence it will be eaſy to ſtate the law by which the ſpring of the air will act on the ſurface of the water below it, as in the following table.

Height of water in air-bar.	*Of the air compressed.*	*Proportion of air's elasticity.*	*Height of the spout.*
$\frac{1}{2}$	$\frac{1}{2}$	2	33
$\frac{2}{3}$	$\frac{1}{3}$	3	66
$\frac{3}{4}$	$\frac{1}{4}$	4	99
$\frac{4}{5}$	$\frac{1}{5}$	5	132
$\frac{5}{6}$	$\frac{1}{6}$	6	165
$\frac{6}{7}$	$\frac{1}{7}$	7	198
$\frac{7}{8}$	$\frac{1}{8}$	8	231
$\frac{8}{9}$	$\frac{1}{9}$	9	264
$\frac{9}{10}$	$\frac{1}{10}$	10	297
$\frac{n-1}{n}$	$\frac{1}{n}$	n	$(n-1)\,33$

Various alterations and improvements have been made from time to time in the conſtruction of Fire-engines. The contrivers of ſome of theſe improvements, as Meſſrs. Bramah, Dickenſon, Simpkin, Rowntree, and Phillips, have ſecured their inventions from infringement by patents; the ſpecifications of moſt of which may be ſeen in the Repertory of Arts and Manufactures. In the year 1785 the ſilver medal and twenty guineas were conferred by the "Society for the Encouragement of Arts," &c. on Mr. Furſt, as a reward for his contrivance to increaſe the effect of engines in extinguiſhing fires; of which the following is a ſhort deſcription: from a platform riſes an upright pole or maſt, of ſuch height as may be judged neceſſary; a gaft ſlides upon it in an aſcending direction, and along both is conveyed the leather hoſe from the engine. The branch or noſe-pipe of the engine projects at the extremity of the gaft; towards which an iron frame is fixed, whence two chains are ſuſpended; and from theſe hang ropes, which ſerve to give an horizontal direction to the branch; while other ropes, that run through proper pullies, and are thus conveyed down the maſt, ſerve likewiſe to communicate a vertical motion to it. By theſe means, the branch or noſe-pipe of the engine is conducted into the window of any room where the fire more immediately rages; and the effect of the water diſcharged is applied in the moſt efficacious manner to the extinguiſhing of the flames.

A very cheap and ſimple fire-engine is that invented in America by Mr. *Benjamin Dearborn*, who communicated it to the American Academy of Arts and Sciences, from whoſe Memoirs for 1794 we extract the following particulars:

Fig. 4. pl. XV. AB and CD are the edges of two planks, confined by four bolts; *a b* and *c d* are two cylindrical barrels, in each of which a piſton, with a valve, is faſtened to the ſpear *e*, and is moved up and down alternately by the motion of the arms EE. Beneath each barrel a hole is made through the plank AB, which is covered with a valve. The arms EE are ſuſpended on the common centre *f*: there are alſo arms parallel to theſe on the oppoſite ſide: *g g* are the ends of handles which are faſtened acroſs the ends of the arms. At *h* a bolt goes acroſs from arm to arm, to which the piece *i k* is affixed, and on which it plays; the lower end of this piece is faſtened to the top of the ſpear *e*. G *l f* is a ſtandard for the purpoſe of ſupporting the arms, to which there is a correſpondent one on the oppoſite ſide; both are notched into the edges of the planks, where they are ſecured by a bolt, which paſſes through them at *l*, and has a nut or fore-lock on the oppoſite ſide. HI, HI, are ſquare braces, anſwering the purpoſe of ducts, through which the water aſcends from the barrels, paſſing through the plank at *m*. KL, KL, are irons in the form of a ſtaple, in order to confine the braces: the lower ends of theſe irons meet, and are ſecured by a bolt paſſing through them, and MN *n o*, which is a piece that goes up through a mortice in the centre of the planks. This piece is ſquare from the lower end, till it reaches the top of the braces; whence they become cylindrical to the top, the upper end being perforated ſufficiently low down, in order to communicate with the braces. OP is an iron ring that ſurrounds the tube, and has two ſhanks which aſcend through the head, which ſcrews on the top at *p q*: *r s* is a ferule nailed round the tube.

Fig. 5. is the ſame engine; the arms and ſtandards being taken off, in order to delineate more clearly the mode of ſecuring the braces; an object which is completely effected by a wedge driven into the mortice *a*: beneath the upper plank *b* is a hole for admitting a paſſage to the bolt, which ſecures the ſtandards. In this figure a ſide view of the head is given, with the pipe in a perpendicular direction.

The machine is confined within a box, ſet on wheels, as in the common fire-engines. The whole is made of wood, excepting the ſpears of the pumps, and a few bolts, &c. The advantages of this machine are, that it can be made in any place where common pumps are manufactured; the interior work will not exceed one-fourth of the price of thoſe which are conſtructed on the uſual plan; and that they are incomparably more eaſy to work than the common ones: circumſtances which ſtrongly recommend the American fire-engine to the attention of the public.

Since the conſtruction of engines for the extinguiſhing of fires has long been conſidered of very great importance, it is no wonder that many perſons have devoted much of their time and talents to this ſubject. Various treatiſes have been written upon it; the chief of which are mentioned below.

Beſchreibung eines waſſerkrahns, welcher in groſſen und gefahrlichen feuerſbrünſten ſehr nutz-lich zu gebrauchen, und mit gar geringen unkoſten angeſchafft werden kann; zugleich in einem kupferſtuck vorgeſtellt. 1665.

Deſcription d'une machine hydraulique, pour éteindre le feu dans les incendies, tirée des regiſtres de L'Acad. Roy. des Sci. de Paris. 1675.

Sur une nouvelle machine pour le feu, par M. de *Reaumur*. Mém. de l'Acad. Roy. des Sci. &c. 1722.

Misſlungene verſuche mit der *Greyliſchen maſchine*, von *Thummig*. Auch. Breſl. Samml. 1721.

A new method of extinguiſhing fires by exploſion and ſuffocation, by Mr. *Godfrey*. 1724.

Lettre de Londres, du 5 Juin, 1761, par M. *Deſchamps*; ſur une expérience publique touchant la nouvelle manière d'eteindre le feu, inventée par M. *Godfrey*, faite par la Société formée pour l'Encouragement des Manufactures et du Commerce en Angleterre.

Mr. *Ambros Godfrey*'s erfindung von geſchwinder auſlöſchung der feuerſbrünſte. Hannöveriſche Beytrage. v. J. 1761.

[The "*Greyliſchen machines*," mentioned above, were introduced into this country by a Mr. *Zachary Greyl*: they were made of wood, and contained only water; they were exhibited before ſeveral of the nobility, but did not meet with encouragement. A few years after, Dr. *Godfrey* produced certain veſſels which in every reſpect ſucceeded. They are ſuppoſed to have been an improvement on Mr. *Greyl*'s, were conſtructed with wood, and filled with a chemical liquor, conſiſting of water, oil of vitriol, and ſal-ammoniac. When thrown into rooms and other places that were purpoſely ſet on fire, they burſt, and by their exploſion completely extinguiſhed the flames: it is to be obſerved, that they were uſeleſs after the roof had fallen in. Theſe contrivances, however, are evidently more calculated for ſhips than to be employed on land; as they would be of great ſervice for ſuppreſſing fires in veſſels at ſea, and might be conſidered as neceſſary a part of their cargo as naval ſtores or ammunition.]

Nouvelle manière d'eteindre les incendies, avec pleuſieurs autres inventions utiles à la ville de Paris; par M. *Moitrell d'Element*. 1725.

Jacob Leupold's beſchreibung und abbildung eines druckwerks mit dem krummen zapfen und ſchwungrad, welches als eine feuerſpritze oder andere maſchine an unterſchiedenen orten kann gebraucht werden. See his Theatri machinarum hydraulicarum. tom. II. cap. 5. 1725.

Deſcription d'une machine ou pompe pour élever l'eau dans les incendies, propoſée par un armurier de Semur en Auxois. See

Receuil mach. et invent. approuvées par l'Acad. Roy. Paris, tom. II. 1735.

Architecture hydraulique, par *Belidor*, tome II. 1739.

A deſcription of the late Mr. *Richard Newſham*'s engines to put out accidental fires. See *Deſaguliers*'s Experimental philoſophy, vol. ii. 1744.

Joh. Gottfr. Dobe, ſchloſſers und ſpritzeumachers in herzberg, nachright von ſeiner neu erfundenen ſpritze mit zwey auſguſſröhen, aus welchen in gleicher quantität und entfernung, jedoch in verſchiedenen direktionen, das waſſer zu gleicher zeit aufgeſpritzt warden kann. Leipz. Int. Bl. 1767.

Abhandlung und berechnung über die neubertſchen ſpritzen, von *Kampe*, ſtadtbauherrn in Göttingen. 1769.

Nachricht von Feuerſpritzen von *J. L. Riepenhauſen*, mechanicus in Göttingen. 1770.

D. Wilh. Gottlieb Haſſe praktiſche abhandlung zu verbeſſerung der feuerſpritzen, welche auf die aufgeſtellte preiſsfrage von Kurfürſtl. Maynziſcher akademie nützlicher Wiſſenſchaften zu Erfurt den beyfall erhalten. Gotha, bey *Karl. Wilhelm Ettinger*. 1778.

Lukas Voch's abhandlung von feuerſpritzen, &c. 1781.

Ueber den zweckmaſſigen gebrauch der feuerſpritze und anderer löſchmaſchinen. Zürch, b. Fueſsli. Tubing. gel. Anz. 1790.

Erfindung einer feuerſpritze, welche ganz ohne röhrwerk, ohne kolben und ventile durch die kraft zweyer menſchen eine überaus groſſe menge waſſer zu einer beträchtlichen höhe in die luft treibt, durch den dritten mann nach allen gegenſtänden gerechtet wird, und mit geringen koſten nebſt derſelben anwendung auf handſpritzen herzuſtellen iſt, von *Karl Imanuel Löſcher*. 1792.

Various fire-engines are deſcribed in the articles HYDROSTATICS and FIRE-*engine*, in the *Engliſh Encyclopædia* and the *Supplement* to that work.

Entwurf die feuerſpritzen mittelſt einer mechaniſchen vorrichtung vor dem einfrieren zu ſichern, nebſt einigen bemerkungen über die löſchanſtalten überhaupt, vorzüglich aber bey brandfällen im winter, bearbeitet von *J. L. J. von Gerſtenbergk*. Jena, in der akademiſchen buckhandl, 1801. p.p. 1 to 89.

This will not be altogether an improper place to ſpeak of the means of extinguiſhing accidental fires in ſhips, recommended by Mr. *Alexander Tilloch*, the editor of the Philoſophical Magazine. Mr. Tilloch begins his paper on this ſubject by ſome account of the theory of combuſtion; in which he takes occaſion to ſtate, that fire is more ſupplied from the oxygen of the air than from the combuſtible body; and that water may itſelf act as an inciter to fire, inſtead of extinguiſhing it, when expoſed to a ſufficient temperature, in circumſtances which ſhall decompoſe it into its conſtituent gaſes, hydrogen, a combuſtible, and oxygen the only ſupporter of flame.

Mr. Tilloch ſtates, alſo, that water acts as an extinguiſher, *merely* by interpoſing itſelf between the flame and the air, and excluding the latter, thus acting "as a wall of ſeparation between the burning materials and the atmoſphere:" for this reaſon he recommends mixing ſand, or mould, or clay, with the water employed to extinguiſh fire, to render its effect in this reſpect more powerful.

Mr. Tilloch ſtrongly ſtates the ſuperior efficacy of cutting off all communication between the burning bodies and the atmoſphere, as the moſt certain means of ſtopping conflagration: wherefore, when this takes place in a ſhip, the hatches ſhould be cloſed, and all hands employed in ſtopping every crevice, by which the air could paſs to the burning body, with oakum or any other matter: by which means the ſhip would become "one large extinguiſher," and the fire go out when it had conſumed the oxygen of the confined air. By this method, if the fire forced its way through the lower deck, it might be ſtopped in the ſecond deck, by cloſing the ports, hatches, and all other apertures belonging to it in every direction.

To haſten the conſumption of the oxygen of the confined air, Mr. Tilloch recommends, before cloſing the hatches, to light as many other fires below, in pots, pans, and other veſſels, as time will permit; likewiſe to light up as many candles as poſſible, each of which conſuming a gallon of air in a minute, will aſſiſt in ſooner rendering the encloſed air unfit for combuſtion.

Mr. Tilloch alſo propoſes, that a quantity of chalk or limeſtone ſhould be ſtowed on board, and an adequate proportion of vitriolic acid; by means of which a quantity of fixed air might be produced, which would alſo aſſiſt in extinguiſhing the fire.

When the flames are ſtopped by theſe means, caution muſt be uſed to carefully ventilate all the encloſed places by every poſſible means, before the men are ſuffered to go down; otherwiſe their inſtant ſuffocation muſt enſue.

When a fire takes place above deck, the uſe of water mixed with ſand or mould is recommended; and the ſtrewing ſand on the decks, three inches thick, both to ſtop and prevent fire in that part, and to form a road by which the men can get at the burning body, ſo as to apply mops wet with the above mixture to it, which Mr. Tilloch thinks would be more effectual than the effect of a fire-engine: in this operation the application of the mop ſhould proceed from below upwards.

It is alſo adviſed to ſeparate the part of the ſhip where fires are moſt likely to originate from the reſt, by air-tight partitions (or bulk-heads), ſo that when a fire happened there it would be only neceſſary to cloſe and caulk up the entrance to this part to put it out.

It is further recommended to cover all the upper works with ſheet-copper, to prevent their taking fire by any accident which might happen on deck, and to encloſe the maſts in the ſame manner, having metallic chains added along the ſhrouds, to ſecure them in caſe of the rigging being burned away.

Some of the particulars in this paper will appear ſo chimerical to a nautical man as to make him ſet leſs value upon the reſt than is due to them: but, as every thing which may tend to ſubdue ſo dreadful an enemy as fire on board a ſhip deſerves being known and conſidered, and as many of the ſuggeſtions in this paper may undoubtedly be applied to moſt important practical purpoſes, we thought it a duty to advert to it; and would beg to refer to No. 82. of the Phil. Mag. for Mr. Tilloch's obſervations at large.

FLAX-MILLS have been conſtructed in great variety: but one of the beſt we are acquainted with is deſcribed in *Gray's Experienced Millwright*, in nearly the following terms.

Fig. 1. pl. XVI. is the *plan*. AA, the water-wheel. CC, the ſhaft or axle upon which it is fixed. BB, a wheel faſtened upon the ſame ſhaft, containing 102 teeth, to drive the pinion D, having 25 teeth, which is fixed upon the middle bruiſing-roller: E, a pinion in which are 10 teeth, turned by the wheel B, which is faſtened upon the under end of the perpendicular ſhaft that carries the ſcutchers. MM, the large frame that ſupports one end of the ſhaft C, and the perpendicular axle. NN are frames in which the rollers turn that break or bruiſe the rough flax. IA and L, the machine and handle to raiſe the ſluice when the water is to be let on the wheel AA to turn it round. GG, doors in the ſide-walls of the mill-houſe. IK, windows to lighten the houſe. HH, ſtairs leading up to the loft.

Fig. 2. *Elevation*. AA, the water-wheel upon its ſhaft CC, on which ſhaft the wheel BB is alſo fixed: this latter wheel containing 102 teeth, to turn the wheel E, having 25 teeth, which is faſtened upon the middle bruiſing-roller. FF is a vertical ſhaft, upon the lower end of which is fixed a pinion having 10 teeth, which is driven by the wheel B. There are two arms that paſs through the ſhaft F; and upon theſe arms are faſtened,

with ſcrewed iron bolts, the ſcutchers that clear the refuſe off the flax. DD, the frames which ſupport one end of the axle C, the vertical ſhaft, and the breaking-rollers: L, a weight ſuſpended by a rope, the other end of which is faſtened to a bearer, as is ſeen in fig. 3. SS a lever, the ſhort arm of which is attached to the frame that the gudgeons of the upper roller turn in; and by puſhing down the long arm, the upper roller is, when neceſſary, ſo raiſed as to be clear of the middle one. NN, the end-walls of the mill-houſe. RR, the couples or frame of the roof. H, a door in the ſide-wall. IK, windows.

Fig. 3. *Section.* AA, the great water-wheel fixed upon its ſhaft, and containing 40 aws or float-boards to receive the water which communicates motion to the whole machinery. BB, a wheel faſtened upon the ſame axle, having, as before mentioned, 102 cogs, to drive the wheel C of 25 teeth which is fixed upon the middle roller, No. 1. The thick part of this roller is fluted, or rather has teeth all round its circumference. Theſe teeth are of an angular form, being broad at their baſe, and thinner towards their outward extremities, which are a little rounded, to prevent them from cutting the flax as it paſſes through betwixt the rollers. The other two rollers Nos. 2. and 3. have teeth in them of the ſame form and ſize as thoſe in the middle roller, whoſe teeth, by taking into thoſe of theſe two rollers, turns them both round. The rough flax is made up into ſmall parcels, which being introduced betwixt the middle and upper rollers, paſs round the middle one; and this either having rollers placed on its off ſide, or being incloſed by a curved board that turns the flax out betwixt the middle and under rollers, when it is again put in betwixt the middle and upper one, round the ſame courſe, until it be ſufficiently broken or ſoftened, and prepared for the ſcutching machine. The bearer in which the gudgeon of the roller No. 1. turns is fixed in the frame at C; and the gudgeons of the rollers Nos. 2. and 3. turn in ſliders that move up or down in grooves in the frames SS. The under roller is kept up to the middle one by the weights DD, ſuſpended by two ropes going over two ſheeves in the frames SS; their other ends being faſtened to a tranſverſe bearer below the ſliders in which the gudgeons of the roller No. 3. turn. The weights DD muſt be conſiderably heavier than the under roller and ſliders, in order that its teeth may be preſſed in betwixt the teeth of No. 1. to bruiſe the flax when paſſing between the rollers. The whole weight of the roller No. 2. preſſes on the flax which paſſes between it and No. 1. There is alſo a box fixed on the upper edge of its two ſliders to contain a parcel of ſtones, or lumps of any heavy metal, ſo that more or leſs weight can be added to the roller, as is found neceſſary. OO, is the large frame that

ſupports one end of the ſhaft which carries the two wheels A, B, and vertical axle FF; on the lower end of which is fixed the pinion turned by the wheel B, and having 10 teeth. In the axle F are arms upon which the ſcutchers are faſtened with ſcrewed bolts, as ſeen at GG, fig. 2. Theſe ſcutchers are incloſed in the cylindrical box EE, having in its curved ſurface holes or porches at which the handfuls of flax are held in, that they may be cleaned by the revolving ſcutchers. HH, the fall or courſe of the water. TT, the ſluice, machine, and handle, for raiſing the ſluice to let the water on the great wheel. The gudgeons of the axles ſhould all turn in cods or buſhes of braſs. KK, the ſide-walls of the mill-houſe. GG, doors. LL, windows.

FLOUR-MILLS are put into motion in various ways: ſometimes the firſt mover is wind, at others water, at others the force of ſteam, at others the muſcular energy of animals. See *Foot-mill*, *Hand-mill*, *Wind-mill*, &c.

The mechaniſm of the grinding part of moſt of theſe is nearly the ſame, and well underſtood; ſo that it will not be neceſſary to enter much into minutiæ, but merely to preſent a general deſcription of a well-conſtructed mill, with any firſt mover; and ſubjoin to this deſcription ſome remarks, rules, and tables.

In plate XVII. we have given a ſection of a *double* Flour-mill, reduced from Gray's Experienced Millwright, with the following account. AA, the water-wheel. BB, its ſhaft or axle. CC, a wheel fixed upon the ſame ſhaft, containing 90 teeth or cogs, to drive the pinion No. 1. having 23 teeth, which is faſtened upon the vertical ſhaft D. No. 2. a wheel fixed upon the ſhaft D, containing 82 teeth, to turn the two pinions FF, having 15 teeth, which are faſtened upon the iron axles or ſpindles that carry the two upper mill-ſtones. EE, the beam or ſill that ſupports the frame on which the under mill-ſtones are laid. GG, the caſes or boxes that encloſe the upper mill-ſtones; they ſhould be about 2 inches diſtant from the ſtone all round its circumference. TT, the bearers, called *bridges*, upon which the under end of the iron ſpindles turn. Theſe ſpindles paſs upward through a hole in the middle of the nether mill-ſtones, in which is fixed a wooden buſh that their upper ends turn in. The top part of the ſpindles, above each wooden buſh, is made ſquare, and goes into a ſquare hole in an iron croſs, which is admitted into grooves in the middle and under-ſurface of the upper mill-ſtone. By this means that ſtone is carried round along with the trundles FF, when turned by the wheel No. 2. One end of the bridges TT is put into mortiſes in fixed bearers, and the other end into mortices in the bearers that move at one end on iron bolts, their other ends hanging by iron rods having ſcrewed nuts, as UU; ſo that when turned forward or backward they raiſe or depreſs the upper mill-ſtones, according as the miller finds it neceſſary. SS, the feeders, in the under end of each of which is a ſquare ſocket that goes upon the ſquare of the ſpindles above the iron croſs or rind, and having three or four branches that move the ſpout or ſhoe, and feed the wheat conſtantly from the hoppers into the hole or eye of the upper mill-ſtone, where it is introduced betwixt the ſtones; and by the circular motion of the upper ſtone acquires a centrifugal force; and proceeding gradually from the eye of the mill-ſtone towards the circumference, is at length thrown out in flour or meal. RR, the ſluice, machine, and handle, to raiſe the ſluice, and let the water on the wheel A to drive it round. No. 3. is a wheel fixed upon the ſhaft D, containing 44 teeth, to turn the pinion No. 4. having 15 teeth, which is faſtened upon the horizontal axle H. On this axle is alſo fixed the barrel K, on which go the two leather belts that turn the wire engine and bolting mill. L, an iron ſpindle, in the under end of which is a ſquare ſocket that takes in a ſquare on the top of the gudgeon of the vertical ſhaft D. There is a pinion M, of 9 teeth, fixed on the upper end of the ſpindle L, to turn the wheel MM, having 48 teeth, which is faſtened upon the axle round which the rope ZZ rolls, to carry the ſacks of flour up to the cooling benches. By pulling the cord OO a little, the wheel MM and its axle are put into motion, in conſequence of that wheel and its axle being moved horizontally, until the teeth of the wheel are brought into contact with thoſe of the pinion at the top of the ſpindle L: and, on the contrary, by pulling the cord PP, the wheel M and its axle are moved in the oppoſite horizontal direction, till they are thrown out of geer with the pinion, and the rotatory motion of that wheel ſtops. But when the ſack of flour is raiſed up to the lever Q, it puſhes up that end of the lever, and of courſe the other end down; by which means the pinion M is diſengaged, and thus that part of the machine ſtops of itſelf. NN are two large hoppers, into which the clean wheat is put to be conveyed down to the hoppers SS, placed on the frame immediately above the mill-ſtones. WW, the ſide-wall of the mill-houſe. V, the couples or frame of the roof. XX, windows to lighten the houſe.

Fig. 1. in the margin repreſents the ſurface of the under grinding mill-ſtone; the way of laying out the roads or channels; the wooden buſh fixed into the hole in its middle, in which the upper end of the iron ſpindle turns round; and the caſe or hoops that ſurround the upper one, which ought to be two inches clear of the ſtone all round its circumference.

Fig. 2. the upper grinding mill-ſtone, and iron croſs or rind in its middle; in the centre of which is a ſquare hole that takes in a ſquare on the top of the iron ſpindle, to carry round the mill-ſtone. When the working ſides or faces of the mill-ſtones are laid uppermoſt, the roads (or channels) muſt lie in the ſame direction in both; ſo that when the upper ſtone is turned over, and its ſurface laid upon the under one, then the channels may croſs each other, which aſſiſts in grinding and throwing out the flour; the ſharp edges of the two furrows then cutting againſt each other like ſciſſors. The roads are likewiſe laid out according to the way the upper ſtone revolves. In thoſe repreſented in the figures the running mill-ſtone is ſuppoſed to turn "*ſun-way*," or as in what is called a *right-handed* mill: but if the ſtone revolves the other way the channels muſt be cut the reverſe of this, and then the mill is termed a *left-handed* one.

The elevation of this mill may be ſeen in Gray's Millwright, pl. XXXI.

It will not be expected that we ſhould allot much ſpace to the *theory* of flour-mills, though it may not be adviſeable to paſs it over entirely. We ſhall therefore give two or three theorems for a ſingle flour-mill of the common conſtruction, which may be applied with facility, ſo far as they are uſeful, to double or triple mills.

Let the weight of the upper ſtone when furrowed be $=W$, the reſiſtance of the corn reduced to the diſtance of the centre of gyration, or at $\frac{2}{3}$ of the radius of the upper ſtone $=R$, then, according to Belidor, $R' = \frac{W}{35}$, while according to Fabre $R = \frac{W}{23}$. But when the upper ſtone to work moſt advantageouſly in every reſpect goes round 60 times in a minute, we have

$$R = \frac{60}{N} \cdot \frac{2\,W}{35} = \frac{60}{450 \div D} \cdot \frac{2\,W}{35} = \frac{D\,W}{131\frac{1}{4}}$$

This, however, would require an upper mill-ſtone of about $7\frac{1}{2}$ feet diameter: for when the diameter of that ſtone is D in feet, and N the moſt advantageous number of rotations in 1 minute, we have, from many obſervations, $N = \frac{450}{D}$, as introduced into the preceding theorem; and this, when $N = 60$, gives $D = 7\frac{1}{2}$.

Let the whole friction when reduced to $\frac{2}{3}$ of the radius of the upper ſtone be repreſented by F, and the effective diſtance of the force or power from the axe on which the ſtone revolves $= r$, the number of teeth in the firſt or commanding wheel $= M$, and the number of ſtaves in the trundle $= m$, the number of revolutions of the water-wheel in 1 minute $= n$, the power which at the diſtance r from the axe of the water-wheel is neceſſary to retain the whole load in equilibrium $= p$; ſo ſhall we have

$$r p = \frac{M}{m} \cdot \tfrac{2}{3} D (R + F)$$

$$\text{whence, } p = \frac{2MD}{3mr} (R + F)$$

$$\text{or, becauſe } \frac{M}{m} = \frac{N}{n},$$

$$\text{we have } p = \frac{2ND}{3nr} (R + F).$$

Let the time in ſeconds in which the water-wheel revolves be $= t$, the velocity with which any point in its circumference moves $= v$, the height due to this velocity being $= h$, $\pi = 3{\cdot}141593$, and $g = 16\tfrac{1}{12}$ feet, then is

$$t = \frac{2\pi r}{v} = \frac{\pi r}{\sqrt{g h}}, \text{ and } n = \frac{60}{t} = \frac{60\sqrt{g h}}{\pi r}$$

$$\text{But it is alſo } n = \frac{m}{M} N = \frac{m}{M} \cdot \frac{450}{D}$$

$$\text{therefore } \frac{450 m}{DM} = \frac{60\sqrt{g h}}{\pi r}, \text{ and } r = \frac{10\, DM \sqrt{g h}}{450 \pi m}$$

An underſhot-wheel produces the greateſt uſeful effect, when the height due to the velocity of the impinging water being H, we have $h = \frac{1}{5} H$, or $v : V :: \sqrt{\frac{1}{5}} : 1 :: 2{\cdot}4$ nearly: retaining theſe as ſufficiently exact for practice, the moſt advantageous radius of the underſhot water-wheel, the water puſhing againſt ſhovels or float-boards, is

$$\varrho = \frac{60\, DM \sqrt{\frac{1}{5} g H}}{450 \pi M} = \frac{0{\cdot}019\, DM \sqrt{g H}}{m}$$

$$\text{or again } \varrho = \frac{{\cdot}0101\, DMV}{m},$$

where V is the velocity of the impinging water.

But in underſhot-mills the fall is ſeldom, if ever, more than 15 or 16 feet: in that caſe the moſt advantageous poſition of the work is to have

$$\frac{M}{m} = \frac{122{\cdot}27}{DV}.$$

Further, let L = the number of pounds of meal which are produced every hour, s = the ſpecific gravity of the upper millſtone, that of water being unity, and B the ſolid content of the ſtone in cubic feet: the remaining letters having the ſame acceptation as before: then

$$\text{for rye and wheat } L = 0{\cdot}021\ D^2 s\, B \frac{M v}{m r} \text{ pounds.}$$

$$\text{for old barley } L = 0{\cdot}06\ D^2 s\, B \frac{M v}{m r} \text{ pounds.}$$

Mr. Ferguſon has made ſome practical obſervations on mills, which, as they are not far from coincidence with the preceding theorems, may be introduced here.

When the diameter of the upper ſtone is about 6 feet, as is generally the caſe, the lower is about an inch more: the upper ſtone then contains about 22½ cubic feet, and weighs rather more than 19000 pounds. A ſtone of this kind ought never to revolve more than 60 or 70 times in a minute; for a more rapid motion would heat the meal. Nor muſt the water-wheel be too large, for in that caſe its angular motion will be too ſlow; on the contrary, if the wheel be too ſmall, it will be deficient in moving power: 18 feet diameter is recommended as a proper medium. And Mr. Ferguſon, on the ſuppoſition that the floats of the wheel ought to move with a third part of the velocity of the water—a ſuppoſition, however, which is not ſtrictly conſiſtent either with theory or with Mr. Smeaton's experiments (ſee vol. I, arts. 473, 483, &c.)—gives the following rules for conſtructing the chief parts of the mill.

1. Meaſure the perpendicular height of the fall of water in feet above that part of the wheel on which the water begins to act, and call that the height of the fall.

2. Multiply this conſtant number 64·2882 (or rather 64⅓) by the height of the fall in feet, and extract the ſquare root of the product, which will be the velocity of the water at the bottom of the fall, or the number of feet the water moves per ſecond.

3. Divide the velocity of the water by 3; and the quotient will be the velocity of the floats of the wheel in feet per ſecond.

4. Divide the circumference of the wheel in feet, by the velocity of its floats; and the quotient will be the number of ſeconds in one turn or revolution of the great water-wheel, on the axis of which is fixed the cog-wheel that turns the trundle.

5. Divide 60 by the number of ſeconds in one turn of the water-wheel or cog-wheel; and the quotient will be the number of turns of either of theſe wheels in a minute.

6. Divide 60 (the number of turns the millſtone ought to have in a minute) by the aboveſaid number of turns; and the quotient will be the number of turns the millſtone ought to have for one turn of the water or cog wheel. Then,

7. As the required number of turns of the millſtone in a minute is to the number of turns of the cog-wheel in a minute, ſo muſt the number of cogs in the wheel be to the number of

ſtaves or rounds in the trundle on the axis of the millſtone, in the neareſt whole number that can be found.

By theſe rules the following table is calculated; in which the diameter of the water-wheel is ſuppoſed 18 feet, and conſequently its circumference 56$\frac{4}{7}$.

The Mill-wright's Table.

Perpendicular height of the fall of water.	Velocity of the water in feet per second.	Velocity of the wheel in feet per second.	Number of turns of the wheel in a minute.	Required number of turns of the millstone for each turn of the wheel.	Nearest num. of cogs and staves for that purpose.		Number of turns of the millstone for one turn of the wheel by these cogs and staves.	Number of turns of the millstone in a min. by these cogs and staves.
					Cogs.	Staves.		
1	8·02	2·67	2·83	21·20	127	6	21·17	59·91
2	11·40	3·78	4·00	15·00	105	7	15·00	60·00
3	13·89	4·63	4·91	12·22	98	8	12·25	60·14
4	16·04	5·35	5·67	10·58	95	9	10·56	59·87
5	17·93	5·98	6·34	9·46	85	9	9·44	59·84
6	19·64	6·55	6·94	8·64	78	9	8·66	60·10
7	21·21	7·07	7·50	8·00	72	9	8·00	60·00
8	22·63	7·56	8·02	7·48	67	9	7·44	59·67
9	24·05	8·02	8·51	7·05	70	10	7·00	59·57
10	25·35	8·45	8·97	6·69	67	10	6·70	60·09
11	26·59	8·86	9·40	6·38	64	10	6·40	60·16
12	27·77	9·26	9·82	6·11	61	10	6·10	59·90
13	28·91	9·64	10·22	5·87	59	10	5·80	60·18
14	30·00	10·00	10·60	5·66	56	10	5·60	59·36
15	31·05	10·35	10·99	5·46	55	10	5·40	60·48
16	32·07	10·69	11·34	5·29	53	10	5·30	60·10
17	33·06	11·02	11·70	5·13	51	10	5·10	59·67
18	34·02	11·34	12·02	4·99	50	10	5·00	60·10
19	34·95	11·65	12·37	4·85	49	10	4·80	60·61
20	35·86	11·92	12·68	4·73	47	10	4·70	59·59

Mr. Fenwick, the author of "Eſſays on Practical Mechanics," made a numerous ſet of experiments on ſome of the beſt mills for grinding corn, in order to form a ſet of tables illuſtrative of the effect of a given quantity of water, in a given time, applied on an overſhot water-wheel of a given ſize. His obſervations, tables, and examples, will form the remaining part of this article.

The quantity of water expended on the water-wheel was meaſured with great exactneſs; the corn uſed was in a medium ſtate of drineſs; the mills, in all their parts, were in a medium working ſtate; the millſtones, making from 90 to 100 revolutions per minute, were from 4$\frac{1}{2}$ to 5 feet in diameter.

The reſult of the experiments was, that the power requiſite to raiſe a weight of 300lbs. avoirdupois, with a velocity of 190 feet per minute, would grind 1 boll of good rye in 1 hour;

but, for the ſake of making the following tables hold in practice, where imperfection of conſtruction exiſts in ſome ſmall degree, it is taken at 300lbs. raiſed with a velocity of 210 feet per minute, (being 1-10th more); and for grinding 2, 3, 4, or 5 bolls of rye per hour requires a power equal to that which could raiſe 300lbs. with the velocity of 350, 506, 677, or 865 feet per minute reſpectively. The difference of the power requiſite to grind equal quantities of wheat from that for rye will be very trifling.

The power required to raiſe a weight of 300lbs. avoirdupois, with a velocity of 390 feet per minute, will prepare properly 1 ton of old rope per week, for the purpoſe of making paper; and for preparing, in like manner, 2 tons of the ſame kind of materials per week, requires a power able to raiſe 300 lbs. with a velocity of 525 feet per minute, the mill working from 10 to 12 hours per day.

A SET OF TABLES, *ſhewing the quantity of water (ale meaſure) requiſite to grind different quantities of corn, from* 1 *to* 5 *bolls (Wincheſter meaſure) per hour, applied on overſhot waterwheels from* 10 *to* 32 *feet diameter; alſo the ſize of the cylinder of the common ſteam-engine to do the ſame work.*

The water-wheel, 10 feet diameter.

Bolls of corn ground per hour.	Quantity of water requiſite in ale gallons, per minute.	Diameter of the cylinder of a ſteam-engine to do the ſame work, in inches.
1	786	12·5
1½	1056	14·6
2	1341	16·75
2½	1617	18·5
3	1894	20·2
3½	2220	21·75
4	2541	23·25
4½	2891	24·75
5	3242	26·25

The water-wheel, 11 ft. diam.

Bolls per hour.	Water, gallons per minute.	Cylinder, in inches.
1	705	12·5
1½	945	14·6
2	1188	16·75
2½	1454	18·5
3	1723	20·2
3½	2014	21·75
4	2306	23·25
4½	2626	24·75
5	2944	26·25

The water-wheel, 12 feet diameter.

Bolls of corn ground per hour.	Quantity of water requiſite in ale gallons per minute.	Diameter of the cylinder of a ſteam-engine to do the ſame work, in inches.
1	655	12·5
1½	873	14·6
2	1091	16·75
2½	1343	18·5
3	1576	20·2
3½	1840	21·75
4	2117	23·25
4½	2408	24·75
5	2700	26·25

The water-wheel, 13 ft. diam.

Bolls per hour.	Water, gallons per minute.	Cylinder, in inches.
1	606	12·5
1½	806	14·6
2	1009	16·75
2½	1234	18·5
3	1458	20·2
3½	1705	21·75
4	1952	23·25
4½	2223	24·75
5	2494	26·25

The waterwheel, 14 feet diameter.

Bolls of corn ground per hour.	Quantity of water requisite in ale gallons, per minute.	Diameter of the cylinder of a steam-engine to do the same work, in inches.
1	564	12·5
1½	740	14·6
2	927	16·75
2½	1140	18·5
3	1353	20·2
3½	1583	21·75
4	1811	23·25
4½	2060	24·75
5	2306	26·25

The water-wheel, 15 feet diameter.

Bolls per hour.	Water, gallons per minute,	Cylinder, in inches.
1	535	12·5
1½	710	14·6
2	894	16·75
2½	1090	18·5
3	1290	20·2
3½	1503	21·75
4	1717	23·25
4½	1967	24·75
5	2211	26·25

The water-wheel, 16 feet diameter.

Bolls per hour.	Water, gallons per minute.	Cylinder, in inches.
1	491	12·5
1½	650	14·6
2	811	16·75
2½	993	18·5
3	1176	20·2
3½	1380	21·75
4	1582	23·25
4½	1802	24·75
5	2023	26·25

The water-wheel, 17 feet diameter.

Bolls of corn ground per hour.	Quantity of water requisite in ale gallons, per minute.	Diameter of the cylinder of a steam-engine to do the same work, in inches.
1	458	12·5
1½	628	14·6
2	770	16·75
2½	943	18·5
3	1117	20·2
3½	1300	21·75
4	1482	23·25
4½	1695	24·75
5	1906	26·25

The water-wheel, 18 feet diameter.

Bolls per hour.	Water, gallons per minute.	Cylinder, in inches.
1	410	12·5
1½	595	14·6
2	730	16·75
2½	860	18·5
3	1054	20·2
3½	1227	21·75
4	1400	23·25
4½	1600	24·75
5	1800	26·25

The water-wheel, 19 feet diameter.

Bolls per hour.	Water, gallons per minute.	Cylinder, in inches.
1	411	12·5
1½	550	14·6
2	690	16·75
2½	845	18·5
3	1000	20·2
3½	1165	21·75
4	1330	23·25
4½	1517	24·75
5	1707	26·25

The water-wheel, 20 feet diameter.

Bolls of corn ground per hour.	Quantity of water requisite in ale gallons, per minute.	Diameter of the cylinder of a steam-engine to do the same work, in inches.
1	392	12·5
1½	530	14·6
2	675	16·75
2½	808	18·5
3	945	20·2
3½	1110	21·75
4	1270	23·25
4½	1445	24·75
5	1623	26·25

The water-wheel, 21 feet diameter.

Bolls per hour.	Water, gallons per minute.	Cylinder, in inches.
1	370	12·5
1½	500	14·6
2	635	16·75
2½	767	18·5
3	900	20·2
3½	1060	21·75
4	1212	23·25
4½	1379	24·73
5	1547	26·25

The water-wheel, 22 feet diameter.

Bolls per hour.	Water, gallons per minute.	Cylinder, in inches.
1	350	12·5
1½	473	14·6
2	594	16·75
2½	722	18·5
3	860	20·2
3½	1007	21·75
4	1153	23·25
4½	1313	24·75
5	1472	26·25

The water-wheel, 23 feet diameter.

Bolls of corn ground per hour.	Quantity of water requisite in ale gallons, per minute.	Diameter of the cylinder of a steam-engine to do the same work, in inches.
1	338	12·5
1½	454	14·6
2	570	16·75
2½	707	18·5
3	824	20·2
3½	964	21·75
4	1124	23·25
4½	1258	24·75
5	1412	26·25

The water-wheel, 24 feet diameter.

Bolls per hour.	Water, gallons per minute.	Cylinder, in inches.
1	327	12·5
1½	436	14·6
2	545	16·75
2½	671	18·5
3	788	20·2
3½	920	21·75
4	1055	23·25
4½	1204	24·75
5	1350	26·25

The water-wheel, 25 feet diameter.

Bolls per hour.	Water, gallons per minute.	Cylinder, in inches.
1	316	12·5
1½	418	14·6
2	520	16·75
2½	635	18·5
3	752	20·2
3½	876	21·75
4	985	23·25
4½	1150	24·75
5	1300	26·25

The water-wheel, 26 feet diameter.

Bolls of corn ground per hour.	Quantity of water requisite in ale gallons, per minute.	Diameter of the cylinder of a steam-engine to do the same work, in inches.
1	303	12·5
1½	403	14·6
2	504	16·75
2½	617	18·5
3	730	20·2
3½	852	21·75
4	975	23·25
4½	1111	24·75
5	1247	26·25

The water-wheel, 27 feet diameter.

Bolls per hour.	Water, gallons per minute.	Cylinder, in inches.
1	293	12·5
1½	385	14·6
2	482	16·75
2½	593	18·5
3	703	20·2
3½	822	21·75
4	940	23·25
4½	1070	24·75
5	1200	26·25

The water-wheel, 28 feet diameter.

Bolls per hour.	Water, gallons inches.	Cylinder, in inches.
1	282	12·5
1½	370	14·6
2	463	16·75
2½	570	18·5
3	676	20·2
3½	791	21·75
4	905	23·25
4½	1030	24·75
5	1153	26·25

The water-wheel, 29 feet diameter.

Bolls of corn ground per hour.	Quantity of water requisite in ale gallons, per minute.	Diameter of the cylinder of a steam-engine to do the same work, in inches.
1	274	12·5
1½	363	14·6
2	455	16·75
2½	557	18·5
3	660	20·2
3½	770	21·75
4	880	23·25
4½	1005	24·75
5	1130	26·25

The water-wheel, 30 feet diameter.

Bolls per hour.	Water, gallons per minute.	Cylinder, in inches.
1	267	12·5
1½	355	14·6
2	447	16·75
2½	545	18·5
3	645	20·2
3½	750	21·75
4	858	23·25
4½	983	24·75
5	1106	26·25

The water-wheel, 31 feet diameter.

Bolls per hour.	Water, gallons per minute.	Cylinder, in inches.
1	256	12·5
1½	340	14·6
2	426	16·75
2½	520	18·5
3	620	20·2
3½	717	21·75
4	827	23·25
4½	940	24·75
5	1058	26·25

The water-wheel, 32 feet diameter.

Bolls of corn ground per hour.	Quantity of water requisite in ale gallons, per minute.	Diameter of the cylinder of a steam-engine to do the same work, in inches.
1	245	12·5
1½	325	14·6
2	406	16·75
2½	496	18·5
3	588	20·2
3½	690	21·75
4	791	23·25
4½	900	24·75
5	1012	26·25

To make the foregoing tables applicable to mills intended to be turned by underſhot or breaſt water-wheels: from Smeaton's experiments it appears that the power required on an underſhot water-wheel, to produce an effect equal to that of an overſhot (to which the tables are applicable), is as 2·4 to 1; and alſo the power required on a breaſt water-wheel, which receives the water on ſome point of its circumference, and afterwards deſcends on the ladle boards, to produce an equal effect with an overſhot water-wheel, is as 1·75 to 1.

A TABLE, *ſhewing the neceſſary ſize of the cylinder of a common ſteam-engine to grind different quantities of corn, from* 1 *to* 12 *bolls (*4 *to* 48 *buſhels Wincheſter meaſure), per hour.*

Bolls of corn ground, per hour.	Diameter of the cylinder, in inches.
1	12·3
1½	14·6
2	16·75
2½	18·5
3	20·2
3½	21·75
4	23·25
4½	24·75
5	26·25
5½	27·25
6	28·1
6½	29
7	29·8
7½	31·1
8	32
8½	33·3
9	34·2
9½	35·2
10	36
10½	37·3
11	38
11½	38·85
12	39·5

N.B. This table will be applicable to any improved steam-engine, as well as that of the common kind, if the ratio of their efficacies is known.

Application of the tables.

Example I.—If a ſtream of water, producing 808 gallons ale meaſure per minute, can be applied on an overſhot water-wheel 20 feet diameter, what quantity of corn will it be able to grind per hour?

Look in the tables under a 20 feet water-wheel, and oppoſite 808 gallons will be found 2½ bolls of corn ground per hour.

Example II.—If a ſtream of water, producing 808 gallons ale meaſure per minute, can be applied to an underſhot water-wheel 20 feet diameter, what quantity of corn can it grind per hour?

It is found by the tables, that, if applied on an overſhot water-wheel 20 feet diameter, the ſtream will grind 2½ bolls per hour; and, from page 194, the power required by the underſhot to that of the overſhot water-wheel, to produce an equal effect, is as 2·4 to 1; therefore, as 2·4 : 1 : : 2·5 : 1·04 bolls of corn ground per hour by means of the ſtream.

Example III.—If a ſtream of water, producing 808 gallons ale meaſure per minute, can be applied on a breaſt water-wheel 20 feet diameter, what quantity of corn can it grind per hour?

It is found by the tables, that, if applied on an overſhot water-wheel of equal ſize, 2½ bolls of corn will be ground per hour; and, from page 194, the power of a breaſt water-wheel to that of an overſhot water-wheel, to produce an equal effect, is as 1·75 to 1; therefore, as 1·75 : 1 : : 2·5 : 1·42 bolls of corn ground per hour by the ſtream.

Example IV.—Of what diameter muſt the cylinder of a common ſteam-engine be made, to grind 10 bolls of corn per hour?

By looking in the table, page 194, oppoſite 10 bolls ground per hour, the diameter of the ſteam cylinder will be found to be 36 inches.

FLY, is a name given to a certain appendage to many machines, either as a *regulator* of their motions, or as a *collector* of power. When uſed as a regulator, the fly is commonly a heavy diſk or hoop balanced on its axis of motion, and at right angles to it: though ſometimes a regulating fly conſiſts of vanes or wings, which as they are whirled round meet with conſiderable reſiſtance from the air, and thus ſoon prevent any acceleration in the motion: but this kind of regulator ſhould rarely, if ever, be introduced in a working machine, as it waſtes much of the moving force. When the fly is uſed as a collector of power, it it is frequently ſeen in the form of heavy knobs at the oppoſite ends of a ſtraight bar; as in the coining-preſs. In arts. 18..23. of the introductory part of this volume the reader will find ſeveral remarks on the nature and operation of the different kinds of flies uſed in machines.

FOOT-MILL, is a mill for grinding corn or any other ſubſtance, moved by the preſſure of the feet of men or animals. In ſome foot-mills, a horſe or an ox is fixed to a ſtall upon a floor above a vertical wheel; and a hole is made in the floor in the place where the hind feet of the animal ſhould ſtand, thus admitting thoſe feet to preſs upon the rim of a wheel, and cauſe the wheel to turn upon its axle, and give motion to the whole mill. But in this kind of machine the animal will be obliged very unnaturally to move his hind feet while his fore feet will be at reſt: and further, the motive force being applied near the vertex of the wheel will act but with little advantage; and the work done will be comparatively trifling.

A much more judicious conſtruction of a foot-mill is given in *G. A. Bockler's Theatrum Machinarum*, publiſhed at Nuremburgh, in 1661. This mill is repreſented in fig. 1. pl. XV. A is an inclined wheel, which is turned by the weight of a man, and the impulſive force of his feet while he ſupports himſelf, or occaſionally puſhes with his hands at the horizontal bar H. The face of this wheel has thin pieces of wood nailed upon it at proper diſtances, to keep the feet of the man from ſlipping while he puſhes the wheel round; and the under ſide has projecting teeth or waves which catch into the cogs of the trundle B, and by that means turn the horizontal ſhaft G with its wheel C: this latter wheel turns the trundle D, the axle of which carries the upper millſtone E. This kind of footmill will anſwer extremely well to grind malt, &c. when no very great power is required. The advantages and diſadvantages of the inclined wheel have been ſtated under the article Crane, when deſcribing the contrivance of Mr. Whyte, which is the ſame as this of Bockler's in reſpect to the wheel.

FORCER, temporary, for a pump, is a contrivance to produce a conſtant ſtream. A very ſimple forcer of this kind has been deviſed by Mr. R. Trevithick: it conſiſts in fixing a barrel with a ſolid piſton along the ſide of the common pump, in ſuch a manner, that the lower ſpace of the additional barrel may communicate with the ſpace between the two valves of the pump; and, laſtly, by connecting the rods ſo that they may work together. This is ſhewn in fig. 1. plate IX.; and the effect is, that when the piſtons are raiſed, the ſpaces beneath, A and B, become filled by the preſſure of the atmoſphere, at the ſame time that the upper column flows out at E. But again, when the piſtons deſcend, the valve C ſhuts, and, conſequently, the water driven by the piſton in B muſt aſcend through A, and continue to produce an equal diſcharge through E in the down ſtroke. *Nich. Journ.* No. 7. N. S.

FOUNTAIN, HERO'S. See HYDRAULIC *machines*, No. 6.

GIBBET, or JIB, of a crane, the projecting beam, upon the extremity of which is fixed a pulley for the rope to paſs over that raiſes the weight: it is repreſented by DEF, in fig. 3. pl. IX. Jibs of the uſual conſtruction turn on two ſolid gudgeons. The rope by which the goods are raiſed paſſes over the upper gudgeon, and is confined between two ſmall vertical rollers, in order that it may conſtantly lead fair with the pulley or ſheave at the extremity of the jib. According to this conſtruction, whenever the crane turns round its axis, the rope is bended ſo as to form an angle more or leſs acute, which cauſes a great increaſe of friction, and produces a continual effort to bring the arm of the jib into a parallel poſition to the inner part of the rope. Theſe inconveniences may appear to be trifling on paper, but in actual practice they are of no ſmall importance, for they neceſſarily imply a much greater exertion of power in raiſing goods, and the application of a conſtant force to keep the jib in the poſition that may be requiſite; while the partial ſtreſs which is exerted on only a few ſtrands of the rope, when bended into an acute angle, infallibly deſtroys it in a very ſhort time.

The ſimple conſtruction propoſed by Mr. J. Bramah obviates all theſe defects, and at the ſame time poſſeſſes the very deſirable property of permitting the jib of what is termed a campſhut or landing crane wholly to revolve round its axis, and to land goods at any point of the circle deſcribed by the arm of the jib.

It conſiſts in perforating the axis or pillar of the crane, and in conducting the rope through this perforation by means of an additional pulley fixed on the top of the arm of the jib. The rope proceeds from the goods which are hoiſted, through a pulley fixed as uſual at the extremity of the jib; it then paſſes over another pulley fixed at the oppoſite extremity of the jib, and is by this pulley conducted through the perforated axis or pillar to a third pulley; whence it is immediately directed to the crane by which the weight is elevated.

It is almoſt unneceſſary to ſtate that the lower axis is uſually fixed in an oil box, and that friction rollers are applied to the axis wherever the circumſtances may render it neceſſary.

When great weights are to be raiſed, as large ſtones from a quarry, or pieces of ordnance from a ſhip to a quay, the crane is commonly a fixed one, and only the gibbet moveable, from which the weight hangs. Here, in the common way of working a crane, the rope of which runs between two vertical rollers, there is often much danger in turning the gibbet upon its axis. A ſmall rope, called a guide-rope, is faſtened to the weight, or to the upper part of the gibbet near its extremity, which a man pulls to bring the weight over the place where it is to be lowered. Now, in performing this, the main rope not continuing parallel to the arm of the gibbet, gives the weight a tendency towards that ſide to which it deviates, and that ſometimes ſo ſuddenly, that without care and much force applied, the load will ſwing with great violence, and do much miſchief. To prevent this, Mr. *Ralph Allen* of Bath, about the year 1728, recommended the following method: Upon the ſhaft of the gibbet let there be fixed an iron wheel with ſeveral teeth or cogs, to be carried round by a pinion fixed upon a horizontal axis, ſuch axis paſſing through the wall or frame-work behind the ſhaft of the gibbet, and having at its further extremity a vertical wheel with handles projecting from the rim in the plane of the wheel. A man ſtanding at this wheel is out of the reach of danger from the load, and by applying a ſmall portion of his ſtrength at the handles of the wheel he can eaſily bring the gibbet and its load to any poſition required, and retain it as long as neceſſary in that poſition. A figure repreſenting this contrivance is given in the Phil. Tranſ. No. 411. and in Ferguſon's Select Lectures.

GIMBALS, a contrivance by means of which barometers, veſſels of oil, mariner's compaſſes, &c. may be ſuſpended ſo as to arrange their upper parts horizontally. The nature of this contrivance will be at once underſtood by ſhewing its application to a mariner's compaſs. It conſiſts of a hoop or ring ſupported upon two pins diametrically oppoſite each other, and iſſuing from the external ſurface of the ring in ſuch a direction that both lie in the ſame diametrical line. When the hoop is ſuſpended on theſe pins it is at liberty to turn freely about the diameter of which they conſtitute the prolongation. The notches or holes of ſupport are diſpoſed horizontally. The compaſs-box itſelf is placed in a ſimilar ring with two projecting pivots; and theſe pivots are inſerted in holes made in the former ring at equal diſtances from each of *its* pivots. If therefore the whole be left at liberty, the compaſs-box may vibrate upon the diametral line of the outer ring, as well as upon a line formed by its own pivots, at right angles to that diametral line. The conſequence of this arrangement is, that the centre of gravity of the compaſs-box will diſpoſe itſelf immediately beneath the interſection of both lines on which it is at liberty to move:—that is to ſay, if the weight of the box and its component parts be properly diſpoſed, the compaſs will aſſume a poſition in which the upper ſurface ſhall be horizontal.

GIN. See CRAB.

GLAZIER'S VICE, is an inſtrument for drawing window lead. See fig. 3. pl. XII. PG, QH, are two axles running in the frame KL, ML. C, D, two wheels of iron caſe-hardened, $1\frac{1}{4}$ inch broad, and of the thickneſs of a pane of glaſs; theſe wheels are fixed to the axles, and run very near one another, their diſtance not exceeding $\frac{1}{10}$ of an inch: acroſs their edges ſeveral nicks are cut, the better to draw the lead through. E, F, are two pinions each of twelve leaves, turning one another and going upon the ends of the axles, which are ſquare, being kept faſt there by the nuts P, Q, which are ſcrewed faſt with a key. A, B, are two cheeks of iron, caſe-hardened, and fixed on each ſide to the caſe with ſcrews; theſe are cut with an opening where the two wheels meet, and ſet ſo near to the wheels as to leave a ſpace equal to the thickneſs of the lead; ſo that between the wheels and the cheeks there is left a hole of the form repreſented at N, which is the ſhape of the lead when cut through. The frame KLML is held together by croſs bars paſſing through the ſides, and ſcrewed on: and a cover is put over the machine to exclude the duſt. The whole is ſcrewed down faſt to a bench by ſcrew nails LL. When the vice is uſed, the lead to be drawn is firſt caſt in moulds, into pieces a foot long, with a gutter on each ſide. One of theſe pieces is taken, and an end of it ſharpened a little with a knife; then, being put into the hole between the wheels, by turning the handle I the lead is drawn through the vice, and receives the form deſigned.

GRAVIMETER, the name given by M. Guyton to an inſtrument for meaſuring ſpecific gravities: he adopts this name rather than either areometer or hydrometer, becauſe theſe latter terms are grounded upon the ſuppoſition that the liquid is always the thing weighed; whereas, with regard to ſolids, the liquid is the known term of compariſon to which the unknown weight is referred.

Guyton's gravimeter is executed in glaſs, and is of a cylindric form, being that which requires the ſmalleſt quantity of fluid, and is on that account preferable, except ſo far as it is neceſſary to deviate for the ſecurity of a vertical poſition. Like Nicholſon's Hydrometer (art. 404. vol. I.) it carries two baſins; one of them ſuperior, at the extremity of a thin ſtem, towards the middle of which the fixed point of immerſion is marked. The other, or lower baſin, terminates in a point; it contains the ballaſt, and is attached to the cylinder by two branches. The moveable ſuſpenſion by means of a hook has the inconvenience of ſhortening the lever which is to ſecure the vertical poſition.

The cylinder is 22 millimetres (0·71 inch) in diameter; and 21 centimetres (6·85 inches) in length. It carries in the upper baſin an additional conſtant weight of 5 grammes (115 grains). Theſe dimenſions might be increaſed ſo as render it capable of receiving a much more conſiderable weight; but this is unneceſſary. M. Guyton has added a piece which he calls the *plongeur*, becauſe in fact it is placed in the lower baſin when uſed, and is conſequently entirely immerſed in the fluid. It is a bulb of glaſs loaded with a ſufficient quantity of mercury, in order that its total weight may be equal to the conſtant additional weight, added to the weight of the volume of water diſplaced by this piece. It will be readily underſtood that the weight being determined at the ſame temperature at which the inſtrument was originally adjuſted, it will ſink to the ſame mark on the ſtem, whether it be loaded with a conſtant additional weight in the upper baſin, or whether the effect of this weight be produced by the additional piece in the lower diſh. From this explanation there will be no difficulty in ſeeing how this inſtrument may be adapted to every caſe in practice.

It may be uſed, 1. for ſolids. It differs not in this reſpect from Nicholſon's hydrometer. The only condition will be, as in his inſtrument, that the abſolute weight of the body to be examined ſhall be rather leſs than the conſtant additional weight, which in this inſtrument is 5 grammes, or 115 grains.

2. For liquids of leſs ſpecific gravity than water, the inſtrument, without the additional weight above mentioned, weighs about 2 decagrammes (459 grains) in the dimenſions before laid down. It would be eaſy to limit its weight to the utmoſt accuracy. We have therefore the range of one-fifth of buoyancy, and conſequently the means of aſcertaining all the intermediate denſities from water to the moſt highly rectified ſpirit of wine, which is known to bear in this reſpect the ratio of 8 to 10 with regard to water.

3. When liquids of greater ſpecific gravity than water are to be tried, the conſtant weight being applied below, by means of the additional piece, which weighs about 6 grammes (138 grains), the inſtrument can receive in the upper baſin more than 4 times the uſual additional weight, without loſing the equilibrium of its vertical poſition. In this ſtate it is capable of ſhewing the ſpecific gravity of the moſt concentrated acids.

4. It poſſeſſes another property common to Nicholſon's inſtrument, namely, that it may be uſed as a balance to determine

the abſolute weight of ſuch bodies as do not exceed its additional load.

5. Laſtly, the purity of the water being known, it will indicate the degrees of rarefaction and condenſation in proportion to its own bulk.

This inſtrument may be readily conſtructed by any workman in glaſs. The additional piece for the lower baſin will require ſome attention to make it perfectly agree with the conſtant upper weight, as to the immerſion of the inſtrument. But this object may, by careful adjuſtment, be aſcertained with the utmoſt certainty and accuracy. The bulb of glaſs is for this purpoſe drawn out to a fine point; a ſufficient quantity of mercury is then introduced to ſink it, and the aperture cloſed with a little piece of wax. The bulb being then placed in the lower baſin of the inſtrument, the upper baſin is to be loaded until the mark on the ſtem becomes accurately coincident with the ſurface of the water. The ſum of the weights added above is preciſely equal to that of the quantity of mercury neceſſary to be added to that in the glaſs bulb; which done, nothing more is needed than to ſeal the point by fuſion, taking care not to change its bulk.

The whole is rendered portable by means of a caſe in which all the delicate parts are ſecured from preſſure, and the heavier parts ſupported in ſuch a manner as to reſiſt the exceſs of motion they are capable of acquiring by virtue of their maſs. This laſt circumſtance is frequently overlooked by ſuch workmen as are employed in the package of inſtruments; whence it neceſſarily follows, that ſome ſtrain or fracture muſt be produced when matters of very unequal denſity are expoſed to receive a common impulſe.

To find the ſpecific gravity of any ſolid by the gravimeter, obſerve this rule: “ From the weight in the upper diſh, when the inſtrument is properly immerſed in the unknown fluid, take the weight which is placed with the body in the ſame ſcale at the like adjuſtment. The remainder is the abſolute weight of the ſolid. Multiply this by the ſpecific gravity of the fluid, and reſerve the product. From the additional weight when the body is placed in the lower baſin, take the weight when it was placed in the upper. The remainder will be the loſs of weight by immerſion. Divide the reſerved product by the loſs by immerſion, and the quotient will be the ſpecific gravity of the ſolid with regard to diſtilled water at the ſtandard temperature and preſſure.”

To find the ſpecific gravity of a fluid proceed thus: “ To the weight of the gravimeter add the weight required in the upper baſin to ſink it in the unknown fluid. Again, to the weight of the gravimeter add the weight required in the ſame manner to ſink it in diſtilled water. Divide the firſt ſum by the latter, and the quotient will be the ſpecific gravity of the fluid in queſtion.",

For figures of the gravimeter, ſee *Annales de Chimie*, tome 21, or Nicholſon's Journal, vol. I. 4to.

HANDMILLS, are commonly uſed for ſome culinary purpoſes, as the grinding of coffee, pepper, and the like. Sometimes handmills of larger ſize are uſed to grind malt, wheat, &c. and in ſuch caſes the hand is generally applied to a winch handle. But in *Beckler's Theatrum Machinarum* there is a deſcription of a mill, in which the effort of a man is applied to a lever moving to and fro horizontally, nearly as in the action of rowing: as this is a very advantageous method of applying human ſtrength, the effort being greatly aſſiſted by the heavineſs of the man in leaning back, we ſhall give a brief deſcription of this kind of mill, which is repreſented in fig. 4. pl. XII. The vertical ſhaft EG carries a toothed wheel C, and a ſolid wheel F; the latter being intended to operate as a regulating fly. Upon the crank AB hangs one end of an iron bar I, the other end of which hangs upon the lever HK; the motion being pretty free at both ends of this bar I. One end of the lever HK hangs upon the fixed hook K, about which as a centre of motion it turns. Then, while a man, by pulling at the lever HK, moves the extremity H from H to N, the bar I acting upon the crank AB gives to the wheels C and F half a rotation; and the momentum they have acquired will carry them on, the man at the lever ſuffering it to turn back from N to H, while the other half of the rotation of the wheels is completed. In like manner another ſufficient pull at the lever HK gives another rotation to the wheel C, and ſo on, at pleaſure. The wheel C turns by its teeth the trundle D, the ſpindle of which carries the upper millſtone, juſt as the ſpindle D carries round the upper ſtone in fig. 1. pl. XV.

In this mill the nearer the end of the bar I upon the lever HK is to the fixed hook K, the eaſier, *cæteris paribus*, will the man work the mill. If the number of teeth in the wheel C be 6 times the number of cogs in the trundle D, then the labourer by making 10 pulls at the lever H in a minute will give 60 revolutions to the upper mill-ſtone in the ſame ſpace of time.

The Society of Arts have lately adjudged a ſilver medal to Mr. Garnett Terry, of City Road, Finſbury-ſquare, for his invention of a mill to grind hard ſubſtances, by means of a wheel turning upon a horizontal axis inſtead of a vertical one, as in the common conſtruction. Mr. Terry has conſtructed this mill on a large ſcale; there is alſo a model depoſited in the collection of that ſociety.

Plate VIII. fig. 4. A. The hopper or receptacle of the articles which are intended to be ground.

B. A ſpiral wire, in the form of a reverſed cone, to regulate the delivery of them.

C. An inclined iron plate, hung upon a pin on its higher end: the lower end reſts on the grooved axis D, and agitates the wire B.

D. The grooved axis, or grinding cylinder, which acts againſt the channelled iron plate E.

F. A ſcrew on the ſide of the mill, by means of which the iron plate E is brought nearer to or removed further from the axis D, according as the article is wanted finer or coarſer.

G. The handle by which motion is given to the axis.

H. The tube from whence the articles, when ground, are received.

⁂ The front of the mill is taken off, in order to ſhew its interior conſtruction.

HEART-WHEEL is the name given in England to a well known method of converting a circuitous motion into an alternating rectilinear one, which is common in cotton-mills. It is an ellipſe turned either on an axle, or by means of a wihch and handle on one of its foci, or its centre, on whoſe edge a moveable point or circle preſſes; the latter receives an alternating motion from the circumference of the ellipſe, and preſſes it in its revolution to different diſtances from the centre of motion. This method was contrived, we believe, by ſir Samuel Morland, about the year 1685. The practical diſadvantages of this contrivance are the inequality of preſſure and of moving force which will be required at different parts of the rotation of the ellipſe, and the conſequent wearing of ſome parts of it much faſter than others, which will render it frequently neceſſary to have new elliptical wheels. A late application of the heart-wheel has been already mentioned, under the word Corning.

HOOKE'S joints, or, as they are often called, *univerſal* joints, have been deſcribed in the introductory part of this volume.

HUNTER'S double screw, was deſcribed in art 161. vol. I.

HYDRAULIC machines, are ſtructures contrived for the purpoſe either of conveying water from one ſituation to another, particularly from a lower to a higher; or, by means of the force or preſſure of water, to perform ſome mechanical operation, as grinding, boring, ſawing. The former kind of hydraulic engines will only be ſpoken of here; the latter being deſcribed under the various heads FLOUR-MILL, FLAX-MILL, SAW-MILL, &c.

1. Of all the machines the ancients invented to raiſe water, it appears that though Archimedes's ſcrew (ſee *Archimedes's* SCREW in this volume) was the moſt curious, the *tympanum*, mentioned by Vitruvius, elevated the greateſt quantity at once: a brief deſcription of this may ſuffice, as preparatory to the account of a machine made in imitation of it, but more ingenious and more perfect.

The *tympanum* is a great hollow wheel, forming a kind of barrel or drum (as its name imports), compoſed of ſeveral planks joined together, well calked and pitched, and having a horizontal axle on which it turns: the interior of this drum is divided into 8 equal ſpaces by as many partitions placed in the directions of the radii; each ſpace or cell has an orifice of about half a foot in the rim of the drum or wheel, ſo ſhaped as to facilitate the admiſſion of the water: moreover, there are 8 hollow channels running contiguous to each other and parallel to the axle of the wheel, each correſponding to one of the 8 large cells; into theſe channels the water paſſes out of the cells juſt mentioned, and, after running along the channels to a convenient diſtance, it eſcapes through orifices into a reſervoir placed juſt under the axle. Thus the water is elevated through a vertical ſpace equal to the radius of the hollow wheel. When the tympanum is uſed to raiſe water from a running ſtream, it is moved by means of float boards which are impelled by the ſtream: but when it is employed to raiſe ſtagnant water, there is commonly a ſmaller wheel on the ſame ſhaft, which is turned by men walking in it, as in the old walking crane. The chief defect of this machine is that it raiſes the water in the moſt diſadvantageous ſituation poſſible: for the load being found always towards the extremity of a radius of the wheel, the arm of the effective lever which anſwers to it increaſes through the whole quadrant the water deſcribes in paſſing from the bottom of the wheel to the altitude of its centre; ſo that the power muſt act in like manner as if it were applied at a winch handle, and cannot, therefore, act uniformly.

2. To remedy this defect M. *de la Faye* deviſed a machine which may here be deſcribed, together with the proceſs of reaſoning that led to it.

When we develope the circumference of a circle, a curve is deſcribed (i. e. the *involute*) of which all the radii are ſo many tangents to the circle, and are likewiſe all reſpectively perpendicular to the ſeveral points of the curve deſcribed, which has for its greateſt radius a line equal to the periphery of the circle evolved. The truth of which is ſhewn by geometricians when treating of the geneſis of evolute and involute curves.

Hence, having an axle whoſe circumference a little exceeds the height which the water is propoſed to be elevated, let the circumference of the axle be evolved, and make a curved canal whoſe curvature ſhall coincide throughout exactly with that of the involute juſt formed: if the further extremity of this canal be made to enter the water that is to be elevated, and the other extremity abut upon the ſhaft which is turned; then in the courſe of the rotation the water will riſe in a vertical direction, tangential to the ſhaft, and perpendicular to the canal in whatever poſition it may be. Thus the action of the weight anſwering always to the extremity of a horizontal radius will be as though it acted upon the invariable arm of a lever, and the power which raiſes the weight will be always the ſame: and if the radius of the wheel, of which this hollow canal ſerves as a bent ſpoke, is equal to the height that the water is to be raiſed, and conſequently equal to the circumference of the axle or ſhaft, the power will be to the load of water reciprocally as the radius of a circle to its circumference, or directly as 1 to 6¼ nearly.

In M. *de la Faye*'s opinion, the machine ought to be compoſed of four of theſe canals: but it has often been conſtructed with 8, as repreſented in fig. 1. pl. XIX. The wheel being turned by the impulſion of the ſtream upon the float-boards, the orifices F, E, D, C, &c. of the curvilinear canals, dip one after another into the water which runs into them; and as the wheel revolves the fluid riſes in the canals *f*, *e*, *d*, *c*, &c. and runs out in a ſtream P from the holes at O; it is received into the trough Q, and conveyed from thence by pipes.

By this conſtruction the weight to be raiſed offers always the ſame reſiſtance, and that the leaſt poſſible, while the power is applied in the moſt advantageous manner the circumſtances will admit of: theſe conditions both fulfilled at the ſame time furniſh the moſt deſirable perfection in a machine. Further, this machine raiſes the water by the ſhorteſt way, namely, the perpendicular, or vertical; in this reſpect being preferable to Archimedes's ſcrew, where the water is carried up an inclined path: and beſides this, each curved channel in this wheel empties all the water it receives in every revolution, while the ſcrew of Archimedes delivers only a ſmall portion of the fluid it is charged with, being often loaded with 20 times as much water as is diſcharged in one rotation; and thus requiring an enormous increaſe of labour when a large quantity is intended to be raiſed by it.

The nature and advantages of this wheel evince very forcibly how far the ſpeculations of geometers are from being ſo unfruitful in uſeful applications, as is often inſinuated by practical men.

3. The wheel juſt deſcribed would we think be the moſt perfect of any that could be employed for raiſing water, had it not the diſadvantage attending the tympanum, which is, that it can only raiſe water to the height of its ſemidiameter. As in many caſes water is to be raiſed higher than the radius of any wheel can well be made for practice, we ſhall next deſcribe a machine called the *Noria*, common in Spain, which raiſes water nearly through a diameter. This Noria conſiſts of a vertical wheel of 20 feet diameter, on the circumference of which are fixed a number of little boxes or ſquare buckets, for the purpoſe of raiſing the water out of the well, communicating with the canal below, and to empty it in a reſervoir above, placed by the ſide of the wheel. The buckets have a lateral orifice, to receive and to diſcharge the water. The axis of this wheel is embraced by four ſmall beams, croſſing each other at right angles, tapering at the extremities, and forming eight little arms. This wheel is near the centre of the horſe-walk, contiguous to the vertical axis, into the top of which the horſe-beam is fixed; but near the bottom it is embraced by four little beams, forming eight arms ſimilar to thoſe above deſcribed, on the axis of the water-wheel. As the mule which they uſe goes round, theſe horizontal arms, ſupplying the place of cogs, take hold, each in ſucceſſion, of thoſe arms which are fixed on the axis of the water-wheel, and keep it in rotation.

This machine, than which nothing can be cheaper, throws up a great quantity of water; yet undoubtedly it has two defects: the firſt is, that part of the water runs out of the buckets and falls back into the well after it has been raiſed nearly to the level of the reſervoir: the ſecond is, that a conſiderable proportion of the water to be diſcharged is raiſed higher than the reſervoir, and falls into it only at the moment when the bucket is at the higheſt point of the circle, and ready to deſcend. Theſe inconveniences are both remedied by the contrivance mentioned in the next paragraph.

4. The *Perſian wheel* is a name given to a machine for raiſing water, which may be turned by means of a ſtream AB acting upon the wheel CDE according to the order of the letters; (fig. 1. pl. XIX.) The buckets *a*, *a*, *a*, *a*, &c. inſtead of being firmly faſtened, are *hung* upon the wheel by ſtrong pins, *b*, *b*, *b*, *b*, &c. fixed in the ſide of the rim; which muſt be made as high as the water is intended to be raiſed above the level of that part of the ſtream in which the wheel is placed. As the wheel turns, the buckets on

the right hand go down into the water, where they are filled, and return up full on the left hand, till they come to the top at K; where they ſtrike againſt the end *n* of the fixed trough M, by which they are overſet, and ſo empty the water into the trough; from whence it is to be conveyed in pipes to any place it is intended for: and as each bucket gets over the trough, it falls into a perpendicular poſition again, and ſo goes down empty till it comes to the water at A, where it is filled as before. On each bucket is a ſpring *r*, which going over the top or crown of the bar *m* (fixed to the trough M) raiſes the bottom of the bucket above the level of its mouth, and ſo cauſes it to empty all its water into the trough.

To determine the due relation of the power and the weight ſo that this wheel may be capable of producing the greateſt effect, the following may be taken as a good approximation. After having fixed the diameter of the wheel, which muſt be ſomething greater than the altitude to which the water is to be raiſed; fix alſo upon an even number of buckets to be hung at equal diſtances round the periphery of the wheel, and mark the poſition of their centres of motion in ſuch a manner that they will ſtand in correſponding poſitions in every quarter of the circle: conceive vertical lines drawn through the centre of motion of each bucket in the riſing part of the wheel; they will interſect the horizontal diameter of the wheel in points at which if the buckets were hung they would furniſh the ſame reſiſtance to the moving force as they do when hanging at their reſpective places on the rim of the wheel. Thus, ſuppoſing there were 18 equidiſtant buckets; then while 8 hung on each ſide a vertical diameter of the wheel there would be 8 on the other ſide, and 2 would coincide with that diameter: in this caſe the reſiſtance ariſing from all the full buckets would be the ſame as if one bucket hung on the prolongation of the horizontal diameter at the diſtance of 2 ſin. 20° + 2 ſin. 40° + 2 ſin. 60° + 2 ſin. 80°, theſe being the ſines to the common radius of the wheel.

To know the quantity of water that each bucket ſhould contain, take $\frac{4}{9}$ of the abſolute force of the ſtream, that is, $\frac{4}{9}$ of the weight of the priſm of water whoſe baſe is the ſurface of one of the float-boards, and whoſe height is that through which water muſt fall to acquire the velocity of the ſtream; ſo have we the power that ſhould be in equilibrio with the weight of water in the buckets of the riſing ſemicircle. Then ſay, as the ſum of the ſines mentioned above is to radius, ſo is the power juſt found to a fourth term, the half of which will be the weight of water that ought to be contained in one bucket. Laſtly, as the velocity of the wheel will be to that of the ſtream nearly as 1 to $2\frac{2}{7}$, the quantity of revolutions it makes in any determinate time becomes known, and, of conſequence, the quantity of water the wheel will raiſe in the ſame time; ſince we know the capacity of each bucket, and the number of them emptied in every revolution of the wheel.

5. Another mechanical contrivance for the purpoſe of raiſing water is a *chain-pump*. This is now generally made from 12 to 24 feet in length; conſiſts of two collateral ſquare barrels, and an endleſs chain of piſtons of the ſame form fixed at proper diſtances. The chain is moved round a coarſe kind of wheel-work, fixed ſometimes at one end, but often at both ends of the machine. The teeth of the wheel-work are ſo contrived as to receive one half of the flat piſtons and let them fold in; and they take hold of the links as they riſe. A whole row of the piſtons (which go free of the ſides of the barrel by about a quarter of an inch) are always lifting when the pump is at work; and, as this machine is generally worked briſkly, the piſtons or pallets bring up a full bore of water in the pump. Chain-pumps are wrought ſometimes by men turning winches, ſometimes by horſes, and ſometimes by the impulſe of a ſtream of water: they are likewiſe ſo contrived that by the continual folding in of the piſtons, ſtones, dirt, or whatever comes in the way, may be cleared off: they are therefore often uſed to drain ponds, ſewers, and remove foul water, when no other pump could be employed.

Chain-pumps are not merely fixed in a vertical poſition, but are often inclined; and in the latter caſe they are in a ſtate of the greateſt perfection, or raiſe the moſt water, when the breadth of the pallets is equal to their diſtance from each other, and the plane is inclined under an angle of 24° 21′.

It is not unuſual for chain-pumps to be erected without a barrel to receive the piſtons, after the manner repreſented in fig. 3. pl. XIX. The pallets are converted into ſquare boxes *s*, *s*, &c. which are raiſed by means of hexagonal axles, each ſide of the hexagon being equal to the diſtance from box to box: the boxes deſcend with their mouths downwards, and ſo enter the water.

Another contrivance for raiſing water ſimilar to the chain-pump is an endleſs rope with ſtuffed cuſhions hung upon it, which, by means of two wheels or drums, are cauſed to riſe in ſucceſſion in the ſame barrel, and to carry water with them. From the reſemblance of this apparatus to a ſtring of beads, it is uſually called *paternoſter-work.* But in this, as well as the chain-pump, the magnitude of the friction is a formidable practical objection.

6. Jets and fountains are not now conſidered as conducive to

picturesque beauty; nor can they be reckoned of much utility, except perhaps in hot climates: we have not therefore deſcribed any in this work. But in the fountain of *Hero* of Syracuſe a principle is introduced which has been found of great utility in larger works; for the head of water is actually lower than the orifice, but the preſſure is communicated by the intervention of a column of air: the conſtruction of this fountain is as follows. It conſiſts of two veſſels KLMN (fig. 5. pl. XIX.) and OPQR, which are cloſe on all ſides. A tube AB, having a funnel at the top, paſſes through the uppermoſt veſſel without communicating with it, being ſoldered into its top and bottom. It alſo paſſes through the top of the under veſſel, where it is likewiſe ſoldered, and reaches almoſt to its bottom. This tube is open at both ends. There is another open tube ST, which is ſoldered into the top of the under veſſel and the bottom of the upper veſſel, and reaches almoſt to its top. Theſe two tubes ſerve alſo to ſupport the upper veſſel. A third tube GF is ſoldered into the top of the upper veſſel, and reaches almoſt to its bottom. This tube is open at both ends, but the orifice G is very ſmall. Now ſuppoſe the uppermoſt veſſel filled with water to the height EN, E *e* being its ſurface a little below T. Stop the orifice G with the finger, and pour in water at A. This will deſcend through AB, and compreſs the air in OQRP into leſs room. Suppoſe the water in the under veſſel to have acquired the ſurface C *c*, the air which formerly occupied the whole of the ſpaces OPQR and KL *e* E will now be contained in the ſpaces *o* P *c* C and KL *e* E; and its elaſticity will be in equilibrio with the weight of the column of water, whoſe baſe is the ſurface E *e*, and whoſe height is A *c*. As this preſſure is exerted in every part of the air, it will be exerted on the ſurface E *e* of the water of the upper veſſel; and if the pipe FG were continued upwards, the water would be ſupported in it to a height *e* H above E *e*, equal to A *c*. Therefore, if the finger be now taken from off the orifice G, the fluid will ſpout up through it to the ſame height as if it had fallen through a tube whoſe altitude is *e* H. So long as there is any water in the veſſel KLNM there will be a diſcharge through the orifice: therefore the play of the fountain will continue whilſt the water contained in the upper veſſel, having ſpouted out, falls down through the pipe AB: the height of the water meaſured from the baſin VAW to the ſurface of the water in the lower veſſel OPQR is always equal to the height meaſured from the top of the jet to the ſurface of the water in the veſſel KLMN. Now, ſince the ſurface E *e* is always falling, and the water in the lower veſſel always riſing, the height of the jet muſt continually decreaſe, till it is ſhorter by the deph of KLMN, which is empty, added to the depth of OPQR, which is always filling; and when the jet is fallen ſo low it immediately ceaſes to play.

7. A machine deſigned to raiſe water to a great height for the irrigation of land, in ſuch ſituations as have the advantage of a ſmall fall, is deſcribed in Dr. Darwin's *Phytologia:* as it depends on the principle of Hero's fountain, it may properly be inſerted here.

Fig. 4. pl. XIX. *a, b,* is the ſtream of water.

b, c, c, repreſents the water-fall, ſuppoſed to be 10 feet.

d, e, are two leaden or iron veſſels, containing a certain quantity of water, which may be computed to be about 4 gallons each.

f, g, h, i, k, l, are leaden veſſels, each holding about two quarts.

o, p, two cocks, each of which paſſes through two pipes, opening the one and cloſing the other.

q, r, is a *water-balance,* that moves on its centre *s;* and by which the two cocks *o* and *p* are alternately turned.

t, u, and *w, x,* are two air-pipes of lead, both internally one inch and a quarter in diameter.

y, z; y, z; y, z; are water-pipes, each being one inch in diameter.

The pipe *b, e, c,* is always full from the ſtream *a, b*: the ſmall ciſterns *g, i, l,* and the large one *d,* are ſuppoſed to have been previouſly filled with water. The fluid may then be admitted by turning the cock *o,* through the pipe *c, e,* into the large ciſtern *e.* This water will preſs the air confined in the ciſtern *e,* up the air-pipe *w, x,* and will force the fluid out of the ciſterns *g, i, l,* into thoſe marked *h, k,* and C.—At the ſame time, by opening B, the water and condenſed air, which previouſly exiſted in the large ciſtern *d,* and in the ſmaller ones marked *f, h, k,* will be diſcharged at B.—After a ſhort time, the water-balance, *q, r, s,* will turn the cocks, and exclude the water, while it opens the oppoſite ones: the ciſterns *f, h, k,* are emptied in their turns by the condenſed air from the ciſtern *d,* as the water progreſſively enters the latter from the pipe *b, c.*

8. A very ingenious application of the ſame principle has been made in the celebrated Hungarian machine, at Chemnitz. The beſt account we have been able to obtain of this is the following.

In fig. 3. pl. XVIII. A repreſents the ſource of water elevated 136 feet above the mouth of the pit. From this there runs down a pipe D of four inches diameter, which enters the top of a copper cylinder B, 8½ feet high, 5 feet diameter, and 2 inches thick, and reaches to within 4 inches of the bottom: it has a cock at I.*

This cylinder has a cock at Q, and a very large one at N. From its top proceeds a pipe VEC two inches in diameter, which goes 96 feet down the pit, and is inſerted into the top of another braſs cylinder C*, which is 6½ feet high, 4 feet diameter, and two inches thick: the latter containing about 83 cubic feet, which is nearly one half of the capacity of the former, viz. 170 cubic feet. There is another pipe FO of 4 inches diameter, which riſes from within 4 inches of the bottom of this lower cylinder, is ſoldered into its top, and riſes to the trough Z which carries off the water from the mouth of the pit. This lower cylinder communicates at the bottom with the water O, which collects in the drains of the mines. A large cock P ſerves to exclude or admit this water: another cock M at the top of this cylinder communicates with the external air.

Now, ſuppoſe the cock I ſhut, and all the reſt open: the upper cylinder will contain air, and the lower cylinder will be filled with water, becauſe it is ſunk ſo deep that its top is below the uſual ſurface of the mine-waters. Shut the cocks Q, N, M, P, and open the cock I. The water of the ſource A muſt run in by the orifice J, and riſe in the upper cylinder, compreſſing the air above it and along the pipe VEC, and thus acting on the ſurface of the water in the lower cylinder. It will therefore cauſe it to riſe gradually in the pipe OF, where it will always be of ſuch a height that its weight balances the elaſticity of the compreſſed air. Suppoſe no iſſue given to the air from the upper cylinder, it would be compreſſed into one-fifth of its bulk by the column of 136 feet high; for a column of 34 feet nearly balances the ordinary elaſticity of the air. Therefore, when there is an iſſue given to it through the pipe VEC, it will drive the compreſſed air along this pipe, and it will expel water from the lower cylinder. When the upper cylinder is full of water, there will be 34 cubic feet of water expelled from the lower cylinder. If the pipe OP had been more than 136 feet long, the water would have riſen 136 feet, being then in equilibrio with the water in the feeding pipe D by the intervention of the elaſtic air; but no more water would have been expelled from the lower cylinder than what fills this pipe. But the pipe being only 96 feet high, the water will be thrown out at Z with a conſiderable velocity. If it were not for the great obſtructions which water and air muſt meet with in their paſſage along pipes, it would iſſue at Z with a velocity of more than fifty feet per ſecond. It iſſues however much more ſlowly, and at laſt the upper cylinder is full of water, and the water would enter the pipe VE and enter the lower cylinder, and, without diſplacing the air in it, would riſe through the diſcharging pipe OP, and run off to waſte. To prevent this there hangs in the pipe VE a cork ball or double cone, by a braſs wire which is guided by holes in two croſs pieces in that pipe. When the upper cylinder is filled with water, this cork plugs up the orifice V, and no water is waſted; the influx at J now ſtops. But the lower cylinder contains compreſſed air, which would balance water in a diſcharging pipe 136 feet high, whereas OP is only 96. Therefore the water will continue to flow at Z till the air has ſo far expanded as to balance only 96 feet of water, that is, till it occupies one-half of its ordinary bulk, that is, one-fourth of the capacity of the upper cylinder, or 42½ cubic feet. Therefore 42½ cubic feet will be expelled, and the efflux at Z will ceaſe; and the lower cylinder is about one-half full of water. When the attending workman obſerves this, he ſhuts the cock I. He might have done this before, had he known when the orifice V was ſtopped; but no loſs enſues from the delay. At the ſame time the attendant opens the cock N the water iſſues with great violence, being preſſed by the condenſed air from the lower cylinder. It therefore iſſues with the ſum of its own weight and of this compreſſion. Theſe gradually decreaſe together, by the efflux of the water and the expanſion of the air; but this efflux ſtops before all the water has flowed out; for there is 42½ feet of the lower cylinder occupied by air. This quantity of water remains, therefore, in the upper cylinder nearly: the workman knows this, becauſe the diſcharged water is received firſt of all into a veſſel containing three-fourths of the capacity of the upper cylinder. Whenever this is filled, the attendant opens the cock P by a long rod which goes down the ſhaft; this allows the water of the mine to fill the lower cylinder, and the air to get into the upper cylinder, which permits the remaining water to run out of it. Thus every thing is brought into its firſt condition; and when the attendant ſees no more water come out at N, he ſhuts the cocks N and M, and opens the cock I, and the operation is repeated.

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* In the figure theſe veſſels are in form of parallelopipeds, and there are ſome pipes and cocks which are not referred to in this deſcription: but this happens, becauſe one diagram is made to ſerve for both the original machine, and Mr. Boſwell's improvements mentioned directly after.

There is a very ſurpriſing appearance in the working of this engine. When the efflux at Z has ſtopped, if the cock Q be opened, the water and air ruſh out together with prodigious violence, and the drops of water are changed into hail or lumps of ice. It is a ſight uſually ſhown to ſtrangers, who are deſired to hold their hats to receive the blaſts of air: the ice comes out with ſuch violence as frequently to pierce the hat like a piſtol bullet. This rapid congelation is a remarkable inſtance of the general fact, that air by ſuddenly expanding generates cold, its capacity for heat being increaſed.

The above account of the procedure in working this engine ſhows that the efflux both at Z and N becomes very ſlow near the end. It is found convenient therefore not to wait for the complete diſcharges, but to turn the cocks when about 30 cubic feet of water have been diſcharged at Z: more work is done in this way. A gentleman of great accuracy and knowledge of theſe ſubjects took the trouble of noticing particularly the performance of the machine. He obſerved that each ſtroke, as it may be called, took up about three minutes and one-eighth; and that 32 cubic feet of water were diſcharged at Z, and 66 were expended at N. The expence therefore is 66 feet of water falling 136 feet, and the performance is 32 raiſed 96, and they are in the proportion of 66 × 136 to 32 × 96, or of 1 to 0,3422, or nearly as 3 to 1. This is ſuperior to the performance of the moſt perfect underſhot mill, even when all friction and irregular obſtructions are neglected; and is not much inferior to any overſhot pump-mill that has yet been erected. When we reflect on the great obſtructions which water meets with in its paſſage through long pipes, we may be aſſured that, by doubling the ſize of the feeder and diſcharger, the performance of the machine will be greatly improved; we do not heſitate to ſay, that it would be increaſed one-third: it is true that it will expend more water; but this will not be nearly in the ſame proportion, for moſt of the deficiency of the machine ariſes from the needleſs velocity of the firſt efflux at Z. The diſcharging pipe ought to be 110 feet high, and not give ſenſibly leſs water. Then it muſt be conſidered how inferior in original expence this ſimple machine muſt be to a mill of any kind which would raiſe 10 cubic feet 96 feet high in a minute, and how ſmall the repairs on it need be, when compared with a mill. And, laſtly, let it be noticed that ſuch a machine can be uſed where no mill whatever can be put in motion. A ſmall ſtream of water, which would not move any kind of wheel, will here raiſe one-third of its own quantity to the ſame height; working as faſt as it is ſupplied.

For theſe reaſons, we think that the Hungarian machine eminently deſerves the attention of mathematicians and engineers, to bring it to its utmoſt perfection, and into general uſe. There are ſituations where this kind of machine may be very uſeful. Thus, where the tide riſes 17 feet, it may be uſed for compreſſing air to ſeven-eighths of its bulk; and a pipe leading from a very large veſſel inverted in it may be uſed for raiſing the water from a veſſel of one-eighth of its capacity 17 feet high; or if this veſſel has only one-tenth of the capacity of the large one ſet in the tide-way, two pipes may be led from it; one into the ſmall veſſel, and the other into an equal veſſel 16 feet higher, which receives the water from the firſt. Thus one-ſixteenth of the water may be raiſed 34 feet, and a ſmaller quantity to a ſtill greater height; and this with a kind of power that can hardly be applied any other way. Machines of this kind are deſcribed by Schottus, Sturmius, Leupold, and other old writers; and they ſhould not be forgotten, becauſe opportunities may offer of making them highly beneficial.

9. Mr. John Whitley Boſwell has deviſed an apparatus which when attached to ſuch a machine as that at Chemnitz will enable it to work itſelf without attendance. The deſcription of this will be preſented to the reader in Mr. Boſwell's own words.

Fig. 3. pl. XVIII. A is the reſervoir, or upper level of water.

B, a chamber made of ſufficient ſtrength to bear the internal preſſure of a column of water the height of A above it, multiplied by its own baſe.

C, a chamber of the ſame ſtrength as B, but of a ſmaller ſize; it is placed at the bottom of the pit from which the water is to be raiſed, and under the level of the water.

Theſe chambers would be ſtronger with the ſame materials, if of a globular or cylindrical form; but the ſquare ſhape is uſed in the drawing merely for the facility of repreſenting the poſition of the parts.

D, a pipe from the reſervoir A which paſſes through the top of B, and ends near its bottom, to convey water from A to B.

E, a pipe from the top of B to the top of C, to convey air from B to C.

F, a pipe from the bottom of C to the level of the ground at the top of the pit, to carry off the water from the pit.

G, a pipe from the bottom of B to carry off the water from it.

H, a veſſel to contain the water uſed in working the cocks; it is only placed on the top of B to ſave the conſtruction of a ſtand on purpoſe for it.

I, a cock, or moveable valve (worked by the lever there repreſented), in the large pipe D.

K, a ſtop-cock in the ſmall pipe which conveys water from D to H. Its uſe is to make the engine work faſter or ſlower, by letting water more or leſs quick into H; or to ſtop it altogether from working when required.

L, a moveable valve, or cock in the ſmall pipe LK. The lever which works it is connected by a ſtrong wire with the lever which works I, and is balanced by a weight at its oppoſite extremity, ſufficient to open both theſe cocks and ſhut N, when not prevented by a counter weight.

N, a cock in the pipe G to open and ſhut it as wanted.

O, a ſelf-moving valve in the pipe F, which permits the water to paſs upwards, but prevents its return.

P, a ſelf-moving valve at the bottom of C, which permits the water to paſs into C, but prevents any from paſſing out of it; it is furniſhed with a grating, to prevent dirt getting in.

R, a veſſel ſuſpended from the levers of I and L, capable of containing a weight of water ſufficient to ſhut them.

S, a veſſel ſuſpended from the lever of N: it muſt contain water enough by its weight to open N: it is connected by a chain to R, to keep it down as long as N is open.

T, a ſyphon paſſing from the bottom of H, near its upper edge, and down again to the mouth of R.

V, a ſelf-moving valve of a ſufficient levity to riſe, when the water in B comes up to it, and cloſe the pipe E; into which no water would elſe paſs from B. A ball-cock, ſuch as uſed in common water ciſterns, would do here.

X, a ſyphon from the bottom of R riſing within an inch of its top, and paſſing down again to the mouth of S.

Y, a ſmall pipe at the bottom of S: this may have a ſtop-cock to regulate it, which, when ſtopped, will alſo ſtop the engine.

The mode of this engine's working is as follows: ſuppoſe the veſſels V, H, R, and S empty of water, and the cocks K and Y open, and the veſſel C full of water. The weight on the lever of L will then open the cocks L and I, on which the water from A will flow into B and H. As the water riſes in B, it will force the air through E into C, which ſtrongly preſſing on the water in C, will force it up through the pipe F, till the water in B riſes to the level of V and cloſes it, at which time H will be full of water (the quantity flowing in being ſo regulated by the cock K), and the water will flow from it through the ſyphon T into the veſſel R, which as it fills ſhuts the cocks I and L, and prevents any more water coming into B and H. When R is full, the water flows through its ſyphon X, which fills S, and by it opens N, which empties B of water, and keeps N open as long as there is any water in H.

When H is empty, B will be ſo too (being ſo regulated by the cock K), on which, in a moment or two, R and S will alſo be empty; which will cauſe the cocks I and L to open, and all things will be again in the ſtate firſt ſuppoſed, for a repetition of the operations deſcribed.

To ſtop the engine, the cocks at K and Y ſhould be ſhut, while S is full of water. To ſet it working, they ſhould be open; and this is all the attendance it will require. As no one but an engineer ſhould attempt to conſtruct ſuch an engine as this, it was uſeleſs to repreſent the manner of connecting the pipes by flaches or otherwiſe; or the proper methods of faſtening and cloſing the parts, which are all well known to ſuch as have made this art their ſtudy. *Nicholſon's Journal*, 4to. vol. I.

In No. 5. of the New Series of Nicholſon's Journal, Mr. Boſwell has made ſome further improvements in the application of the Hungarian machine.

10. The *Spiral pump* is a very curious hydraulic engine, which operates on nearly the ſame principle as the Hungarian machine. The firſt engine of this kind, of which we have ſeen any account, was invented and erected by H. Andreas Wirtz, a tinplate-worker of Zurich, at a dye-houſe in Limmat, in the vicinity of that city. It conſiſts of a hollow cylinder, like a very large grindſtone, turning on a horizontal axis, and partly plunged in a ciſtern of water. The axis is hollow at one end, and communicates with a vertical pipe. This cylinder or drum is formed into a ſpiral canal, by a plate coiled up within it like the main ſpring of a watch in its box; only the ſpires at a diſtance from each other, ſo as to form a conduit for the water of uniform width. This ſpiral partition is well joined to the two ends of the cylinder, and no water eſcapes between them. The outermoſt turn of the ſpiral begins to widen about $\frac{3}{4}$ths of a circumference from the end, and this gradual enlargement continues nearly a ſemicircle, this part being called the horn: it then widens ſuddenly, forming a ſcoop or ſhovel. The cylinder is ſo ſupported that this ſhovel may, in the courſe of a rotation, dip ſeveral inches into the water. As the cylinder turns upon its axis, the ſcoop dips and takes up a certain quantity of water before it emerges again. This quantity is ſufficient to fill the horn; and this again is nearly equal in capacity to the outermoſt uniform ſpiral round.

After the ſcoop is emerged, the water paſſes along the ſpiral by the motion of it round the axis, and drives the air before it into the riſing pipe, where it eſcapes. In the mean time, air comes into the mouth of the ſcoop; and when the ſcoop again dips into the water, it again takes in ſome of that fluid. Thus there becomes a part filled with water, and a part filled with air. Continuing this motion, a ſecond [illegible] of water will be received, and another of air. The water in any turn of the ſpiral will have its two ends on a level; and the air between the ſucceſſive columns of water will be in its natural ſtate; for ſince the paſſage into the riſing pipe or main is open, there is nothing to force the water and air into any other poſition. But ſince the ſpires gradually diminiſh in their length, it is plain that the column of water will gradually occupy more and more of the circumference of each. At laſt it will occupy a complete turn of ſome ſpire that is near the centre; and when ſent further in by the continuance of the motion, ſome of it will run back over the top of the ſucceeding ſpire. Thus it will run over into the right-hand ſide of the third ſpire; and conſequently will puſh the water of this ſpire backwards, and raiſe its other end, ſo that *it* will likewiſe run over backwards *before* the next rotation be completed. At length this change of diſpoſition will reach the outermoſt ſpire, and ſome water will run over into the horn and ſcoop, and finally into the ciſtern.

But as ſoon as water gets into the riſing pipe, and riſes a little into it, it ſtops the eſcape of the air when the next ſcoop of water is taken in. Hence there are then two columns of water acting againſt each other by hydroſtatic preſſure, and the intervening column of air: they muſt compreſs the air between them, and the water and air columns will now be unequal: this will have a general tendency to keep the whole water back, and cauſe it to be higher on the left or riſing ſide of each ſpire than on the right or deſcending ſide: the exceſs of height being juſt ſuch as produces the compreſſion of the air between that and the preceding column of water. This will go on increaſing as the water mounts in the riſing pipe; for the air next to the riſing pipe is compreſſed at its inner end with the weight of the whole column in the main: and it muſt be as much compreſſed at its outer end, which muſt be done by the water column without it; and this column exerts this preſſure partly by reaſon that *its* outer end is higher than its inner end, and partly by the tranſmiſſion of the preſſure on its outer end by air, which is ſimilarly compreſſed from without. Thus it will happen that each column of water being higher at its outer than at its inner end, compreſſes the air on the water column beyond or within it, which tranſmits this preſſure to the air beyond *it*, adding to it the preſſure ariſing from its own want of level at the ends. Conſequently, the greateſt compreſſion, viz. that of the air next the main, is produced by *the ſum of all the tranſmitted preſſures*; and theſe are the ſum of all the differences between the elevations of the inner ends of the water columns above their outer ends: and the height to which the water will riſe in the main will be juſt equal to this ſum.

Suppoſe the left-hand ſpaces of each ſpire to be filled with water, and the right-hand ſpaces filled with air, as is ſhewn, in regard to one ſpire, in fig. 3. pl. XVII. There is a certain gradation of compreſſion which will keep things in this poſition: for the ſpaces manifeſtly decreaſe in arithmetical progreſſion; and ſo do the hydroſtatic heights and preſſures: if, therefore, the air be denſe in the ſame progreſſion all will be in hydroſtatical equilibrium. Now this may obviouſly be produced by the mere motion of the machine; for ſince the denſity and compreſſion in each air column is ſuppoſed inverſely as the magnitude of the column, the quantity of air is the ſame in all; therefore the column firſt taken in will paſs gradually inwards, and the increaſing compreſſion will cauſe it to occupy preciſely the whole right-hand of every ſpire. The gradual diminution of the water columns will be produced, during the motion, by the water running over backwards at the top from ſpire to ſpire, and ultimately coming out by the ſcoop. Since the hydroſtatic height of each water column is now the greateſt poſſible, viz. the diameter of the ſpire, it is evident that this diſpoſition of the air and water will raiſe the water to the greateſt height. This diſpoſition may be obtained thus; let CB be a vertical radius of the wheel, C being the center, and B the higheſt point [the figure may eaſily be drawn]; upon CB, take CL to CB, as the denſity of the external air to its denſity in the laſt column next the riſing pipe or main; that is, make CL to CB as 34 feet (the height of the column of water which balances the preſſure of the atmoſphere), to the ſum of 34 feet, and the height of the riſing pipe: then divide BL into ſuch a number of turns that the ſum of their equal diameters ſhall be equal to the height of the main; laſtly, bring a pipe ſtraight from L to the centre C. Such is the conſtruction of the ſpiral pump, as originally invented by Wirtz: it certainly indicates very conſiderable mechanical knowledge and ſagacity.

But when the main is very high this conſtruction will require either an enormous diameter of the drum, or many turns of a very narrow pipe. In ſuch caſes it will be much better to make the ſpiral in the form of a corkſcrew, than of this flat form like a watch-ſpring. The pipe which forms the ſpiral may be wrapped round the fruſtrum of a cone, whoſe greateſt diameter is to the leaſt (which is next to the riſing pipe) in the proportion juſt aſſigned to CB and CL. By this conſtruction the water will ſo ſtand in every round as to have its upper and lower ſurfaces tangents to the top and bottom of the ſpiral, and the water columns will occupy the whole aſcending ſide of the machine, while the air occupies the deſcending ſide. This form is far preferable to the flat form; it will allow us to employ many turns of a large pipe, and therefore produce a great elevation of a large quantity of water.

The ſame thing will be ſtill better accompliſhed by wrapping the pipe on a cylinder, and making it gradually tapering to the end, in ſuch a manner that the contents of each ſpire may be the ſame as when it is wrapped round the cone. It will raiſe the water to a greater height (though certainly with an increaſe of the impelling power), by the ſame number of ſpires, becauſe the vertical or preſſing height of each column is greater.

In the preceding deſcription of this machine, that conſtruction has been choſen which made its principle and manner of working moſt evident, namely, that which contained the ſame material quantity of air in each turn of the ſpiral, more and more compreſſed as it approaches to the riſing pipe. But this is not the beſt conſtruction: for we ſee that in order to raiſe water to the height of a column of 34 feet, the air in the laſt ſpire is compreſſed into half its ſpace; and the quantity of water delivered into the main at each turn is but half what was received into the firſt ſpire, the reſt flowing back from ſpire to ſpire, and being diſcharged at the ſpout.

But the conſtruction may be ſuch that the quantity of water in each ſpire may be the ſame that was received into the firſt; by which means a greater quantity (double in the inſtance now given) will be delivered into the main, and raiſed to the ſame altitude by very nearly the ſame force. This may be done by another proportion of the capacity of the ſpires; either by a change of their caliber, or of the diameters of the ſolid on which they are folded. Suppoſe the bore to be uniform throughout, the diameters muſt ſo vary that the conſtant column of water and the column of air, compreſſed to the proper degree, may occupy the whole circumference. Let A be the column of water which balances the preſſure, and H the height to which the water is to be raiſed. Let A be to A + H as 1 to *m*. Then it is plain that *m* will repreſent the denſity of the air in the laſt ſpire, if its natural denſity be 1, becauſe it is preſſed by the column A + H while the common air is preſſed by A. Let 1 repreſent the conſtant water column, and conſequently it will be nearly equal to the air column in the firſt ſpire: then the whole circumference of the laſt ſpire muſt be $1 + \frac{1}{m}$, in order to hold the water 1, and to compreſs the air into the ſpace $\frac{1}{m}$ or $\frac{A}{A+H}$. The circumference of the firſt ſpire is 1 + 1 or 2: and if D and *d* be the diameters of the firſt and laſt ſpires we have $2 : 1 + \frac{1}{m} :: D : d$, or $2m : m + 1 :: D : d$. If, therefore, a pipe of uniform bore be wrapped round a conic fruſtrum, of which D and *d* are the end diameters, the ſpirals will be very nearly ſuch as will anſwer the purpoſe. It will not be *quite* exact, for the intermediate ſpirals will be rather too large: the conoidal fruſtrum ſhould in ſtrictneſs be formed by the revolution of a logarithmic curve. With ſuch a ſpiral the full quantity of water which was confined in the firſt ſpire will find room in the laſt, and will be ſent into the main at every rotation. This is a very great advantage, eſpecially when the water is to be much raiſed. The ſaving of power by this change of conſtruction is always proportional to the greateſt compreſſion of the air.

The chief difficulty in any of theſe forms is in determining the form and poſition of the horn and the ſcoop; yet on this the performance of the machine greatly depends. The following inſtructions will render this tolerably eaſy. Let ABEO (fig. 3. pl. XVII.) repreſent the firſt or outermoſt ſpire, of which the axis is C. Suppoſe the machine immerged up to the axis in the water whoſe ſurface is VV′: it has been ſeen that it is moſt effective when the ſurfaces KB and O *n* of the water columns are diſtant from each other the whole diameter BO of the ſpire. Let therefore the pipe be firſt conceived of equal caliber to the very mouth E *e*, which we ſuppoſe to be juſt about to dip into the water: the ſurface O *n* is kept there in oppoſition to the preſſure of the water column BAO by the compreſſed air contained in the quadrant OE, and in the quadrant which lies behind EB: and this compreſſion is ſupported by the columns behind, between this ſpire and the riſing pipe. But the air in the outermoſt quadrant EB is in its natural ſtate, becauſe it as yet communicates with the external air. When, however, the mouth E *e* has come round to A, it will not have the water ſtanding in it in the ſame manner, leaving the half ſpace BEO filled with compreſſed air; for it took in and confined only what filled the quadrant BE. It is obvious, therefore, that the quadrant BE muſt be ſo ſhaped as to take in and confine a much greater quantity of air; ſo that when it has come to A, the ſpace BEO may contain air ſufficiently denſe to ſupport the column AO. But this is not enough: for when the wide mouth now at A *a′* riſes up to the top, the ſurface of the water in it riſes alſo, becauſe the part AO *o a′* is more capacious than the part of uniform bore OE *e o* that ſucceeds it, and that cannot contain all the water which it previouſly held. Since then the water in the ſpire riſes above A, it will preſs the water back from O *n* to ſome other poſition *m′ n′*, and the preſſing height of the water column will be diminiſhed by this riſing on the other ſide of O. Hence it will appear that the horn muſt begin to widen, not from B, but from A, and muſt occupy the whole ſemicircle ABE; while its capacity muſt be to the capacity of the oppoſite ſide of uniform bore as the ſum of BO and the height of a column of water which balances the atmoſphere to the height of that column: for then the air which filled it when of the common denſity will fill the uniform ſide BEO, when compreſſed ſo as to balance the vertical column BO. But even this is not ſufficient: for it has not taken water enough. When it dipped into the ciſtern at E it carried air down with it, and the preſſure of the water in the ciſtern cauſed that fluid to riſe into it a little way; and ſome water muſt have come over at B from the other ſide, which was drawing narrower. When, therefore, the horn is in the poſition EOA it is not full of water: conſequently, when it comes into the ſituation OAB it cannot be full, nor can it balance the air on the oppoſite ſide. Hence ſome will come out at O, and riſe up through the water. The horn muſt therefore extend at leaſt from O to B, or occupy half the circumference; and it muſt contain at leaſt twice as much water as would fill the ſide BEO. Nay, if it be much larger, there may be no diſadvantage; becauſe the ſurplus of air which it takes in at E will be diſcharged as the end E *e* of the horn riſes from O to B, and it will leave the preciſe quantity that is wanted. The overplus water will be diſcharged as the horn comes round to dip again into the ciſtern.

We muſt alſo ſecure the proper quantity of water. When the machine is ſo much immerſed as to be up to its axis in water, the capacity which thus ſecures the proper quantity of air will alſo take in the proper quantity of water. But it may be erected ſo as that the ſpirals ſhall not even reach the water: and in this caſe it will anſwer the purpoſe if a ſcoop or ſhovel be joined to the horn, and ſo formed as to take in at leaſt as much water as will fill the horn. This is all that is wanted in the beginning of the motion along the ſpiral, and more than is neceſſary when the water has advanced to the ſucceeding ſpire; but the overplus is diſcharged in the way juſt mentioned. The ſcoop, it ſhould be obſerved, muſt be very open on the ſide next the axis, that it may not confine the air as it enters the water; for this would hinder it from receiving enough of that fluid.

As an example we ſhall give the dimenſions of a machine erected at Florence, whoſe performance correſponded extremely well with the theory. The ſpiral is formed on a cylinder of 10 feet diameter, and the diameter of the pipe is 6 inches. The ſmaller end of the horn is of the ſame diameter; it occupies $\frac{1}{4}$ of the circumference, and is 7·8 inches wide at the outer end: here it joins the ſcoop, which lifts as much water as fills the horn, which contains 4340 Swediſh cubic inches, each = 1·577 Engliſh. The machine makes 6 revolutions in a minute, and raiſes 1354 pounds of water, or 22 cubic feet, 10 feet high in a minute. Thus it raiſes more than $\frac{10}{11}$ths of what the theory would lead us to expect, and yet it is not perfect; for the ſpiral is throughout of equal caliber, and is formed on a cylinder inſtead of a conoid.

In this machine the friction is ſo inconſiderable that it need not be mended: but the great excellency is, that whatever imperfections there may be in the arrangement of the air and water columns, it only affects the elegance of the execution, cauſing the water to make a few more turns in the ſpiral before it can mount to the required height; but it waſtes no power, becauſe the power employed is always in proportion to the ſum of the vertical columns of water in the riſing ſide of the machine, and the altitude to which the water is raiſed by it is in the very ſame proportion. The machine ſhould be made to move very ſlow, that the water be not always dragged up by the pipes, which would cauſe more to run over from each column and diminiſh the preſſure of the remainder. If the riſing pipe be made wide, and thus room be made for the air to eſcape freely upwards through the water, it will riſe to the height aſſigned; but if the pipe be narrow, ſo that the air cannot riſe freely, it riſes almoſt as ſlowly as the water; and by this circumſtance the water mixed with the air is raiſed to a much greater height, and this with hardly any augmentation of the power. Thus it is that the great performance of the Florentine machine (which is almoſt triple what a man can do with the beſt conſtructed pump) is accounted for. Laſtly, we may obſerve that the entrance into the riſing pipe ſhould be no wider than the laſt part of the ſpiral; and it would be adviſeable to divide it into four channels by a thin partition, and then to make the riſing pipe very wide, and to put into it a number of ſlender rods, which would divide it into ſeveral ſlender channels that would ſerve completely to entangle the air among the water: this procedure will greatly increaſe the heights to which the heterogeneous column may be carried.

We earneſtly recommend the application and improvement of this machine to practical engineers: the principles on which its theory depends are confeſſedly intricate; but when judiciouſly conſtructed it is very powerful and effective in its operations: on which accounts we are ſorry that hitherto it has not, as far as we recollect, been deſcribed in more than two Britiſh works, the *Tranſactions of the Society of Arts*, for 1776, and the *Encyclopædia Britannica.*

11. Deſaguliers deſcribes, in the ſecond volume of his Experimental Philoſophy, a very ſimple contrivance to raiſe water, which is this: to one end of a rope is fixed a large bucket, having a valve at its bottom, opening upwards; to the other end is faſtened a ſquare frame, and the cord is made to paſs over two pulleys, each of about 15 inches diameter (and fixed in a horizontal plane), in ſuch manner that as the bucket deſcends the frame aſcends with equal velocity, and *vice verſa.* The frame is made to run freely upon 4 vertical iron guide-rods paſſing through holes at its four corners: and when the bucket is filling with water at the well, the frame ſtands at the horizontal plane to which the water is to be raiſed: when the bucket is full a man ſteps upon the frame (his weight, together with that of the frame, exceeding the weight of the veſſel and its contained water); this gives an aſcending motion to the bucket, and cauſes the valve in its bottom to cloſe. When the bucket is raiſed to the proper height a hook fixed there catches into a haſp at the ſide of the bucket, turns it over, and cauſes it to empty its water into a trough which conveys it where it is required: at this time the man and the deſcending frame have arrived at a platform which prevents their further deſcent, where the man remains till he finds the bucket above is empty; when he ſteps from the frame, and runs up a flight of ſtairs to the place from which he deſcended: the bucket in the mean while, being ſomewhat heavier than the frame, deſcends to the water, and raiſes the frame to its original poſition. Thus the work is continued, the man being at reſt during his deſcent, and labouring in the aſcent.

Deſaguliers employed in this kind of work a "*tavern drawer*," who weighed 160 lbs. whom he deſired to go up and down 40 ſteps of 6½ inches each (in all about 22 feet) at the ſame rate he would go up and down all day. He went up and down twice in a minute: ſo that allowing the bucket with a quarter of a hogſhead in it to weigh 140 lbs. he is able to raiſe it up through 22 feet twice in a minute: this Deſaguliers eſtimates as equivalent to a whole hogſhead raiſed 11 feet in a minute; and rather exceeds what he has aſſigned as a maximum of human exertion.

This machine is in many caſes not only the moſt ſimple, but the *beſt* that can be deviſed; yet it is one that without due precautions is likely to be a very bad one. The frame on which the man ſteps muſt be brought up to its place again by a preponderancy in the machine when unloaded: it ſhould arrive preciſely at the ſame time with the man; but it may arrive ſooner or later. If ſooner, it is of no uſe, and waſtes power in raiſing a counterpoiſe which is needleſsly heavy, or in fact leſs water is elevated than the man is able to elevate; if later, there is a loſs of time. Hence the perfection of this truly ſimple machine requires the judicious combination of two maximums, each of which varies in a ratio compounded of two other ratios. It will not be difficult, however, to adjuſt the proportions of the weight of the bucket and that of the frame: for if B denote the weight of the bucket, F that of the frame, and ϕ the force neceſſary to overcome the friction and the inertia of the pulleys, g denoting $32\frac{1}{6}$ feet, t the time occupied in walking up the ſteps, and s the ſpace aſcended or deſcended, then muſt B and F be ſo adjuſted as to ſatisfy the following equation, viz.

$$s = \frac{B-F}{B+F+\phi} \cdot \frac{1}{2} g t^2.$$

12. If there be a ſpring affording but a ſmall quantity of water, or having but a ſmall fall, it is poſſible by the loſs of ſome of the water to raiſe the reſt to ſupply a gentleman's ſeat, or any place where it is wanted; but in a leſs quantity than what runs waſte, if the place to which the water is to be raiſed is higher than the ſpring or reſervoir from which the water falls. Schottus long ago contrived an engine for this purpoſe: but the firſt who put ſuch a thing in execution was *Gironimo Finugio*, at Rome, in 1616; and the firſt in this country was *George Gerves*, a carpenter, who, in the year 1725, erected an engine called the Multiplying-wheel Bucket-engine, at the ſeat of Sir John Cheſter, at Chichley, in Buckinghamſhire. This engine was much approved by Sir Iſaac Newton, Dr. Deſaguliers, and Mr. Beighton, and was certainly very ingenious. The water from a ſpring deſcended in a large bucket hanging by a cord from an axle, while a ſmaller quantity was raiſed from the ſame place by a cord hanging from a wheel on the ſame axle: a fly and other regulating apparatus were added, to make the engine work itſelf, which it did for many years without being out of order. As a whole, however, the contrivance is complex; and we are not aware that any other engines of the ſame kind have been erected. A deſcription, with a plate, may be ſeen in Deſaguliers's ſecond volume.

Mr. *H. Sarjeant*, of Whitehaven, contrived a very cheap engine for raiſing water, for which the Society for the Encouragement of Arts awarded him a ſilver medal in the year 1801. A ſketch of this ſimple invention is given in fig. 2. pl. XIX.

This engine was erected at Irton-hall, which is ſituated on an aſcent of 60 or 61 feet perpendicular height: at the foot of this elevation, about 140 yards diſtant from the offices, there runs a ſmall ſtream of water; and, in order to procure a conſtant ſupply of that neceſſary fluid, the object was to raiſe ſuch ſtream to the houſe for culinary and domeſtic uſes. With this view, a dam was formed at a ſhort diſtance above the current, ſo as to cauſe a fall of about four feet: the water was then conducted through a wooden trough, into which a piece of leaden pipe, two inches in diameter, was inſerted, and part of which is delineated at A.

The ſtream of this pipe is directed in ſuch a manner as to run into the bucket B, when the latter is elevated; but, as ſoon as it begins to deſcend, the ſtream paſſes over it, and flows progreſſively to ſupply the wooden trough or well, at the foot of which ſtands the forcing-pump C, being three inches in diameter.

D is an iron cylinder attached to the pump-rod, which paſſes through it: ſuch cylinder is filled with lead, and weighs about 240 lbs. This power works the pump, and forces the water to aſcend to the houſe through a pipe one inch in diameter, and which is 420 feet in length.

At E is fixed a cord, which, when the bucket approaches to within four or five inches of its loweſt projection, extends, and opens a valve in the bottom of the veſſel through which the water is diſcharged.

An engine in a great degree ſimilar to this was erected ſome years ago by the late James Spedding, eſq. for a lead mine near Keſwick, with the addition of a ſmaller bucket which emptied itſelf into the larger near the beginning of its deſcent, without which addition it was found that the beam only acquired a libratory motion, without making a full and effective ſtroke.

To anſwer this purpoſe in a more ſimple way, Mr. Sarjeant conſtructed the ſmall engine in ſuch manner as to finiſh its ſtroke (ſpeaking of the bucket end) when the beam comes into an horizontal poſition, or a little below it. By this means the lever is virtually lengthened in its deſcent in the proportion of the radius to the coſine, of about thirty degrees, or as ſeven to ſix nearly, and conſequently its power is increaſed in an equal proportion.

It is evident, that the opening of the valve might have been effected, perhaps better, by a projecting pin at the bottom; but Mr. S. choſe to give an exact deſcription of the engine as it ſtands. It has now been ſome years in uſe, and completely anſwers the purpoſe intended.

The only artificers employed, except the plumber, were a country blackſmith and carpenter; and the whole coſt, excluſive of the pump and pipes, did not amount to 5£.

In a letter, dated Whitehaven, April 28, 1801, Mr. Sarjeant obſerves, that the pump requires about eighteen gallons of water in the bucket to raiſe the counter-weight, and make a freſh ſtroke in the pump; but it makes three ſtrokes in a minute, and gives about a half-gallon into the ciſtern at each ſtroke. He adds, " I ſpeak of what it did in the drieſt part of laſt ſummer; when it ſupplied a large family, together with work-people, &c. with water for all purpoſes, in a ſituation where none was to be had before, except ſome bad water from a common pump which has been ſince removed. But the above ſupply being more than ſufficient, the machine is occaſionally ſtopped to prevent wear, which is done by merely caſting off the ſtring of the bucket valve."

13. Mr. *Benjamin Dearborn*, whoſe ſimple fire-engine has already been mentioned, has contrived an hydraulic engine which may be conveniently added to a common pump, and thereby renders it uſeful in further elevating water, and particularly in extinguiſhing fires: the following deſcription of his apparatus is extracted from the *Memoirs of the American Academy*.

Plate XIX. fig. 7. A, B, C, D, repreſents a pump, the form of which is ſimilar to that of the pumps commonly employed on ſhip-board.

E, the ſpout.

F, a ſtopper.

D, *d*, a plank-cap, that is fitted to the pump, and provided with leather on its lower ſurface; being ſecured by the ſcrews *a*, *b*: in the centre is a hole, through which the ſpear of the pump paſſes, and round which a leather collar is made, as repreſented at the letter *c*.

g, a nut for the ſcrew *b*.

f, a ſquare piece of wood that is nailed acroſs one end of the plank-cap, through both which the ſcrew *a* is introduced: a hole is made through ſuch piece and the cap, that communicates with the bore of the pump.

G, G, a wooden tube, which may be of any requiſite length, and conſiſt of any number of joints: it is made ſquare at the lower extremity, and perforated for the reception of the cock; the upper end being made with a *nice* ſhoulder.

e, a wooden cock that opens or ſhuts the communication between the pump and the tube; being furniſhed on the oppoſite ſide with a handle and with a lock, in caſe it ſhould be found neceſſary.

h, *h*, are two ferules, the object of which is to prevent the tube from ſplitting.

H, H, braces, each of which ought to be croſſed over an other, as nearly at right angles as poſſible.

i, *i*, are irons in form of a ſtaple, which ſurround the tube, and paſs through the braces; their ends being perforated with holes for fore-locks.

K, L, M, N, is a head made of five pieces of wood; *k*, *l*, *m*, *n*, a ſquare piece, in the lower part of which is a hole for the reception of the extremity of the tube, and which piece reſts on the ſhoulder *o*, *p*; to the lower end of this head is nailed a piece of leather, with a hole in its centre, ſimilar to that made in the wood. Another piece of leather of the ſame form is placed on the top of the tube, and between both is a circle of thin plate-braſs; the two pieces of leather and the braſs being preſſed between the lower end of the head and the ſhoulder of the tube. Their edges are delineated at *o*, *p*.

K, N, and L, M, are the edges of two pieces of plank, of a ſimilar width with the head, to which they are cloſely nailed; each being provided with a tenon, that paſſes through a mortice in the end of the piece O, P: both tenons have holes for a fore-lock at *q*.

O, P, a piece of plank of the ſame width as the ſides; the centre of which is perforated, in order that the tube may paſs through; and in each end of which is a mortice for the reception of the tenons.

N, M, a cap.

r, *r*, are two pieces nailed to the ſide of the tube; the lower extremity of each is provided with a truck, with a view to leſſen the friction of the head in its horizontal revolution.

q, *q*, repreſent fore-locks, the deſign of which is to faſten down the head, and prevent the water from eſcaping at the joint *o*, *p*.

Q, R, is a wooden conductor; the extremity marked with the letter Q being ſolid, while the oppoſite end, R, is bored with a ſmall auger.

s, a bolt that paſſes through the conductor and head, and being ſecured on the back with a fore-lock or nut: this bolt is rounded near the head, and ſquare in the middle.

t, *u*, *w*, *x*, repreſents a piece of iron or braſs, deſigned to prevent the head of the bolt from wearing into the wood.

S, S, are ropes for the direction of the conductor.

Fig. 8. repreſents the head without ſuch conductor.

a, *b*, *c*, *d*, is a thick braſs plate, the centre of which is perforated, ſo as to admit a paſſage to impurities, that might otherwiſe obſtruct the conductor: for which purpoſe a piece of leather is nailed under it to the head. The ſquare hole in the centre is adapted to the ſize of the bolt, which it prevents from turning. The conductor has a hollow cut round the bolt on the inſide, of the ſame ſize as the circle of holes in the braſs round ſuch cavity is nailed, on the face of the conductor, a piece of leather, that plays on the margin of the braſs-plate when the conductor is in motion.

In the concluſion of his Memoir, Mr. *Dearborn* obſerves, that he has raiſed a tube of 30 feet on his pump; and, though the ſeverity of the ſeaſon had prevented him from completing it, ſo that one perſon only could work at the brake, yet he is enabled to throw water on a contiguous building, the neareſt part of which is 37 feet from the pump, and between 30 and 40 feet in height.

14. It will be expected that ſome notice ſhould be taken in this place of two celebrated hydraulic engines, viz. the *water-works at London-bridge*, and thoſe at *Marly*. Of theſe, the former has been ſo often deſcribed in well-known Engliſh works, that a minute deſcription appears quite unneceſſary: the latter will be briefly deſcribed under the article *Marly* in this volume. Other contrivances for raiſing water, ſuch as the *centrifugal machine*, *preſſure engines*, *pumps*, and Archimedes's *screw*, are likewiſe treated under the reſpective words.

After all, it is not poſſible within the limits to which the ſubject of hydraulic engines muſt neceſſarily be confined in this work, to deſcribe a tenth part of thoſe which, by the ingenuity of their conſtruction, and their great utility, deſerve the attention of thoſe who are likely to be engaged in the erection of ſuch machines. To ſupply the deficiency in ſome meaſure, a catalogue is here added of the moſt important and valuable writings on theſe kinds of engines.

Deſcriptio machinæ hydraulicæ curioſæ conſtructa *Joh. Geor. Faudieri.* Venet. 1607.

Nouvelle invention de lever l'eau plus haut que la ſource, avec quelque machines mouvantes par le moyen de l'eau, &c. par *Iſaac de Caus.* 1657.

Joſephi Gregorii a Monte Sacr. Principia phyſico-mechanica diverſarum machinarum ſeu inſtrumentorum pneumatices ac hydraulices. Venet. 1664.

Nouvelle machine hydraulique, par *Francini.* Journ. des Sçav. 1669.

[An account of this machine is likewiſe given in the Architecture hydraulique of Belidor, tom. 2. and in the 2d vol. of Deſaguliers's Experimental philoſophy: in both which performances many other hydraulic machines are deſcribed.]

An undertaking for raiſing water, by *Sir Samuel Moreland.* Phil. Trans. 1674. No. 102.

An hydraulick engine, by . . . . Phil. Trans. 1675. No. 128.

A cheap pump, by Mr. *Conyers.* Phil. Trans. 1677. No. 136.

M. *de Hautefeuille*, Reflexions ſur quelques machines à elever les eaux, avec ſa deſcription d'une nouvelle pompe, ſans frottement et ſans piſton, &c. 1682.

Elevation des eaux par toute ſorte des machines, reduite à la meſure, au poids, à la balance, par le moyen d'un nouveau piſton et corps de pompe, et d'un nouveau mouvement cyclo-elliptique, et rejetant l'uſage de toute ſorte de manivelles ordinaires, par le Chevalier *Morland.* 1685.

A new way of raiſing water, enigmatically propoſed, by Dr. *Papin.* Phil. Trans. 1685. No. 173. The ſolutions by Dr. Vincent and Mr. R. A. in No. 177.

M. *du Torax*, Nouvelles machines pour épuiſer l'eau des foundations, qui, quoi très ſimples, font un effet ſupprenant. 1695. Journ. des Sçav. 1695. p. 293.

An engine for raiſing water by the help of fire, by Mr. *Tho. Savery.* Phil. Trans. 1699. No. 253.

D. Papin, Nouvelle manière pour lever l'eau par la force du feu: à Caſſel. 1707.

Memoire pour la conſtruction d'une pompe qui fournit continuellement de l'eau dans le reſervoir, par M. *de la Hire*, Mem. Acad. Sci. Paris. 1716.

Deſcription d'une machine pour elever des eaux, par. M. *de la Faye*, Mem. Acad. Sci. Paris. 1717.

Joh. Jac. Bruckmann's und *Joh. Heinr. Weber*'s Elementarmaſchine, oder univerſal-mittel bey allen waſſer-hebungen. Caſſel. 1720.

Jacob Leupold, Theatri machinarum hydraulicarum. 1724, 1725.

Joh. Frid. Weidleri Tractatus de machinis hydraulicis toto terrarum orbe maximis Marlyenſi et Londinenſi, &c. 1727. Vide Act. erudit. Lips. 1728.

A deſcription of the water-works at London-bridge, by *H. Beighton*, F. R. S. Phil. Trans. 1731. No. 417.

An account of a new engine for raiſing water, in which horſes or other animals draw without any loſs of power (which has never yet been practiſed); and how the ſtrokes of the piſton may be made of any length, to prevent the loſs of water by the too frequent opening of valves, &c. by *Walter Churchman.* Phil. Trans. 1734.

Sur l'effet d'une machine hydraulique propoſée par M. Segner, par M. *Leon. Euler*, Mem. Acad. Sci. Berlin. 1750.

Application de la machine hydraulique de M. Segner à toutes ſortes d'ouvrages, et de ſes avantages ſur les autres machines hydrauliques, par M. *Leon. Euler*, Mem. Acad. Sci. Berlin. 1751.

[M. *Segner*'s machine is no other than the ſimple yet truly ingenious contrivance known by the name of *Barker's mill*, which had been deſcribed in the 2d volume of Deſaguliers's Philoſophy, ſome years before the German profeſſor made any pretenſions to the honour of the invention. The theory of it is likewiſe treated by *John Bernoulli* at the end of his Hydraulics.]

Recherches ſur une nouvelle manière d'elever de l'eau propoſée par M. *de Mour*, par M. *L. Euler*, Mem. Acad. Berlin. 1751.

Diſcuſſion particulière de diverſes manières d'elever de l'eau par le moyen des pompes, par M. *L. Euler*, Mem. Acad. Ber. 1752.

Maximes pour arranger le plus advantageuſement les machines deſtinées à elever de l'eau par le moyen des pompes, par M. *L. Euler*, Mem. Acad. Ber. 1752.

Reflexions ſur les machines hydrauliques, par M. le Chevalier *D'Arcy*, Mem. Acad. Sci. Paris. 1754.

Memoire ſur les pompes par M. le Chevalier *de Borda*, Mem. Acad. Sci. Paris. 1768.

Dan. Bernoulli Expoſitio theoretica ſingularis machinæ hydraulicæ. Figuri helvetiorum, exſtructæ. Nov. Com. Acad. Petrop. 1772.

Abhandlungen von der waſſerſchraube, von *D. Scherffer*, Prieſter. Wien. 1774.

Recherches ſur les moyens d'exécuter ſous l'eau toutes ſortes de travaux hydrauliques, ſans employer aucun epuiſement, par M. *Coulumb*. 1779.

Saemund Magnuſſen Holm, Efterretning om ſkye pumpen. Kiobenhavn. 1779.

Moyen d'augmenter la viteſſe dans le mouvement de la vis d'Archimede ſur ſon axe, tire des mémoires manuſcrits de M. *Pingeron*, ſur les arts utiles et agréables. Journ. d'Agric. Juin, 1780.

The theory of the ſyphon, plainly and methodically illuſtrated. 1781. (Richardſon.)

Memoria ſopra la nuova tromba funiculare umiliata, dal Can. *Carlo Caſtelli*. Milano. 1782.

Diſſertation de M. *de Parcieux*, ſur le moyen d'elever l'eau par la rotation d'une corde verticale ſans fin. Amſterdam et Paris. 1792.

Theorie der wirziſchen ſpiral pumpe, erläutert von *Heinr. Nicander*. Schwed. Abhandl. 1783.

Jac. Bernoulli, Eſſai ſur une nouvelle machine hydraulique propre à elever de l'eau, et qu'on peut nommer Machine Pitotienne. Nov. Act. Acad. Petrop. 1786.

K. Ch. *Langsdorf*'s Berechnungen über die vortheilhæftere benutzung angelegter ſammelteiche zur betreibung der maſchinen. Act. Acad. Elect. Mogunt. 1784, 1785.

Nicander's Theorie der ſpiral pumpe. 1789.

Nouvelle architecture hydraulique, par M. *Prony.* 1790, 1796.

A ſhort account of the invention, theory, and practice of fire-machinery; or introduction to the art of making machines vulgarly called ſteam-engines, in order to extract water from mines, convey it to towns, and jets d'eaux in gardens; to procure water-falls for fulling, hammering, ſtamping, rolling, and corn-mills, by *W. Blakey.* 1793. (Egerton.)

To theſe may be added the Tranſactions of the Society of Arts, the Repertory of Arts, *Nicholſon's* Philoſophical Journal, and *Tilloch's* Philoſophical Magazine, in different places.

HYDROMETERS. See vol. I. arts. 401, 409.

HYGROMETER, or HYGROSCOPE, or NOTIOMETER, an inſtrument contrived to meaſure the humidity of the air.

The inſtruments hitherto invented for this purpoſe, have not been attended with that accuracy which there was reaſon to expect and to hope for. We have hygrometers, it is true, which indicate that the air has been more or leſs moiſt; but they have often this fault, that they indicate a greater degree of moiſture than really exiſts in the atmoſphere: beſides, they are not comparable; that is to ſay, it is not poſſible by their means to compare the moiſture of one day, or of one place, with that of another. It may not, however, be improper to deſcribe a few of the contrivances of this kind, if it be only that their utility may be examined.

1. As fir wood is very ſuſceptible of participating in the dryneſs and moiſture of the atmoſphere, ſome have conceived the idea of applying this property to the conſtruction of an hygrometer. For this purpoſe, a ſmall, very thin fir board, is placed acroſs between two vertical immoveable pillars, ſo that the fibres ſtand in a horizontal direction; for it is in the lateral direction, or that tranſverſal to its fibres, that fir and other kinds of wood are extended by moiſture. The upper edge of the board ought to have a ſmall rack, fitted into a pinion, connected with a wheel, and the latter with another wheel, having on its axis an index. It may be eaſily perceived, that by theſe means the leaſt motion communicated by the upper edge of the board to the rack, by its riſing or falling, will be indicated in a very ſenſible manner by the index; conſequently, if the motion of the index be regulated in ſuch a manner, that from extreme dryneſs to extreme moiſture it may make a complete revolution, the diviſions of this circle will indicate how much the preſent ſtate of the atmoſphere is diſtant from either of theſe extemes.

This invention is ingenious, but it is not ſufficient. The wood retains its moiſture a long time after the air has loſt that with which it was charged; beſides, the board gradually becomes leſs ſenſible to the impreſſions of the air, and therefore produces little or no effect.

2. Suſpend a ſmall circular plate by a fine ſtring, or piece of catgut, faſtened to its centre of gravity, and let the other end of the ſtring be attached to a hook. According as the air is more or leſs moiſt, you will ſee the ſmall plate turn round in one direction or in another.

The hygrometers commonly ſold are conſtructed on this principle. They conſiſt of a kind of box, the fore part of which repreſents a building with two doors. On one ſide of the metal plate which turns round, ſtands the figure of a man with an umbrella, to defend him from the rain, and on the other a woman with a fan. The appearance of the former of theſe figures indicates damp, and that of the other dry, weather. This pretended hygrometer can ſerve for no other purpoſe than to amuſe children; for the philoſopher muſt obſerve that, as the variations of humidity are tranſmitted to this inſtrument only by degrees, it will indicate moiſture or drought when the ſtate of the atmoſphere is quite contrary.

3. Some have tried to conſtruct an hygrometer, by making faſt a piece of catgut at one extremity, winding it backwards and forwards over different pulleys, and ſuſpending from its other extremity a ſmall weight, behind which is placed a graduated ſcale. Others diſpoſe the extremity of the catgut in ſuch a manner, as to cauſe it to move an index round a graduated plate, the different degrees of which indicate the dryneſs or moiſture of the atmoſphere. This inſtrument, however, is ſubject to the ſame inconveniences as that before mentioned.

4. Put into one ſcale of a balance any ſalt that attracts the moiſture of the air, and into the other a weight, in exact equilibrium with it. The ſcale containing the ſalt will ſink down during damp weather, and thereby indicate that ſuch is the ſtate of the atmoſphere. An index, to determine the different degrees of drought or moiſture, may be eaſily adapted to it.

This inſtrument however is worſe than any of the reſt; for a ſalt immerſed in moiſt air becomes charged with a great deal of humidity, but loſes it very ſlowly when the air becomes dry: fixed alkali of tartar even imbibes moiſture till it falls in *deliquium*, that is to ſay, till it is reduced to a liquid or fluid ſtate.

5. Muſic may be employed to indicate the dryneſs or moiſture of the air. The ſound of a flute is higher during dry than during moiſt weather, and the ſtring of a violin exhibits the ſame phenomenon; but neither of theſe can ſhew the immediate ſtate of the air in regard to dryneſs or humidity.

6. M. De Luc's contrivance for an hygrometer is on this

principle. Finding that even ivory ſwells with moiſture, and contracts with dryneſs, he made a ſmall and very thin hollow cylinder of ivory, open only at the upper end, into which is fitted the under or open end of a very fine long glaſs tube, like that of a thermometer. Into theſe is introduced ſome quickſilver, filling the ivory cylinder, and a ſmall part of the length up the glaſs tube. The conſequence is this: when moiſture ſwells the ivory cylinder, its bore or capacity grows larger, and conſequently the mercury ſinks in the fine glaſs tube; and, *vice verſa*, when the air is drier, the ivory contracts, and forces the mercury higher up the tube of glaſs. It is evident that an inſtrument thus conſtructed is in fact alſo a thermometer, and muſt neceſſarily be affected by the viciſſitudes of heat and cold, as well as by thoſe of dryneſs and moiſture; or that it muſt act as a thermometer as well as an hygrometer. The contrivances in the ſtructure and mounting of this inſtrument are deſcribed in the Philos. Trans. vol. 63, art. 38; where it may be ſeen how the above imperfection is corrected by ſome ſimple and ingenious expedients, employed in the original conſtruction and ſubſequent uſe of the inſtrument; in conſequence of which, the variations in the temperature of the air, though they produce their full effects on the inſtrument as a thermometer, do not interfere with or embarraſs its indications as an hygrometer.

7. In the Philoſ. Tranſ. for 1791, M. De Luc has given a ſecond paper on hygrometry. This has been chiefly occaſioned by a Memoir of M. De Sauſſure on the ſame ſubject, entitled Eſſais ſur l'Hygrometrie, in 4to, 1783. In this work M. De S. deſcribes a new hygrometer of his conſtruction, on the following principle. It is a known fact that a hair will ſtretch when it is moiſtened, and contract when dried: and M. De Sauſſure found, by repeated experiments, that the difference between the greateſt extenſion and contraction, when the hair is properly prepared, and has a weight of about 3 grains ſuſpended by it, is nearly one 40th of its whole length, or one inch in 40. This circumſtance ſuggeſted the idea of a new hygrometer. To render theſe ſmall variations of the length of the hair perceptible, an apparatus was contrived, in which one of the extremities of the hair is fixed, and the other, bearing the counterpoiſe abovementioned, ſurrounds the circumference of a cylinder, which turns upon an axis to which a hand is adapted, marking upon a dial in large diviſions the almoſt inſenſible motion of this axis. About 12 inches high is recommended as the moſt convenient and uſeful: and to render them portable, a contrivance is added, by which the hand and the counterpoiſe can be occaſionally fixed.

But M. De Luc, in his Idées ſur la Meteorologie, vol. i.

anno 1786, ſhews that hairs, and all the other animal or vegetable hygroſcopic ſubſtances, taken lengthwiſe, or in the direction of their fibres, undergo contrary changes from different variations of humidity; that when immerſed in water, they lengthen at firſt, and afterwards ſhorten; that when they are near the greateſt degree of humidity, if the moiſture be increaſed, they ſhorten themſelves; if it be diminiſhed, they lengthen themſelves firſt before they contract again. Theſe irregularities, which render them incapable of being true meaſures of humidity, he ſhews to be the neceſſary conſequence of their organic reticular ſtructure. De Sauſſure takes his point of extreme moiſture from the vapours of water under a glaſs bell, keeping the ſides of the bell continually moiſtened; and affirms, that the humidity is there conſtantly the ſame in all temperatures; the vapours even of boiling water having no other effect than thoſe of cold. De Luc, on the contrary, ſhews that the differences in humidity under the bell are very great, though De Sauſſure's hygrometer was not capable of dicovering them; and that the real undecompoſed vapour of boiling water has the directly oppoſite effect to that of cold, the effect of extreme dryneſs: and on this point he mentions an intereſting fact, communicated to him by Mr. Watt, viz. that wood cannot be employed in the ſteam-engine for any of thoſe parts where the vapour of the boiling water is confined, becauſe it dries ſo as to crack as if expoſed to the fire.

To theſe charges of M. De Luc, a reply is made by M. De Sauſſure, in his Defence of the Hair Hygrometer, in 1788; where he attributes the general diſagreement between the two inſtruments to irregularities of M. De Luc's; and aſſigns ſome aberrations of his own hygrometer, which could not have proceeded from the above cauſe, but to its having been out of order, &c.

This has drawn from M. De Luc a ſecond paper on hygrometry, publiſhed in the Philoſ. Tranſ. for 1791, p. 1. and 389. This author here reſumes the four fundamental principles which he had ſketched out in the former paper, viz. 1ſt, That a fire is a ſure, and the only ſure, means of obtaining extreme dryneſs. 2d. That water, in its liquid ſtate, is a ſure, and the only ſure means of determining the point of extreme moiſture. 3d. There is no reaſon, *à priori*, to expect from any hygroſcopic ſubſtance, that the meaſurable effects produced in it by moiſture, are proportional to the intenſities of that cauſe. But, 4th, perhaps the comparative changes of the dimenſions of a ſubſtance, and of the weight of the ſame or other ſubſtances, by the ſame variations of moiſture, may lead to ſome diſcovery in that reſpect. On theſe heads M. De Luc expatiates at large in this paper, ſhewing the imperfections of M. De Sauſſure's principles of hygrometry, and particularly as to a hair, or any ſuch ſubſtance when extended lengthwiſe, being properly uſed as an hygrometer. On the other hand, he ſhews that the expanſion of ſubſtances acroſs the fibres, or grain, renders them, in that reſpect, by far the moſt proper for this purpoſe. He chooſes ſuch as can be made very thin, as ivory or deal ſhavings, but he prefers whalebone, as far the beſt.

The preceding general deſcription of the principal hygrometers will, we truſt, be ſufficient to ſhew that great imperfection and uncertainty attends the uſe of any of them; and, at the ſame time, to juſtify us in not entering more into detail reſpecting the conſtruction of theſe inſtruments.

JACK, an inſtrument in common uſe for raiſing heavy timber, or very great weights of any kind; being a powerful combination of teeth and pinions, and the whole incloſed in a ſtrong wooden ſtock or frame BC, and moved by a winch or handle HP; the outſide appearing as in fig. 5. pl. VIII. In fig. 6. the wheel or rack work is ſhewn, being the view of the inſide when the ſtock is removed. Though it is not drawn in the juſt proportions and dimenſions, for the rack AB muſt be ſuppoſed at leaſt four times as long in proportion to the wheel Q, as the figure repreſents it; and the teeth, which will be then four times more in number, to have about 3 in the inch. Now if the handle HP be 7 inches long, the circumference of this radius will be 44 inches, which is the diſtance or ſpace the power moves through in one revolution of the handle: but as the pinion of the handle has but four leaves, and the wheel Q ſuppoſe 20 teeth, or 5 times the number, therefore to make one revolution of the wheel Q, it requires 5 turns of the handle, in which caſe it paſſes through 5 times 44 or 220 inches: but the wheel having a pinion R of 3 leaves, theſe will raiſe the rack 3 teeth, or one inch, in the ſame ſpace. Hence, then, the handle or power moving 220 times as faſt as the weight, will raiſe or balance a weight of 220 times its own energy. And if this be the hand of a man who can ſuſtain 50 pounds weight, he will, by help of this jack, be able to raiſe, or ſuſtain, a weight or force of 11000 lb. or about 5 tons weight.

This machine is ſometimes open behind from the bottom almoſt up to the wheel Q, to let the lower claw, which in that caſe is turned up as at B, draw up any weight. When the weight is drawn or puſhed ſufficiently high, it is kept from going back by hanging the end of the hook S, fixed to a ſtaple, over the curved part of the handle at *b*.

The Society of Arts rewarded a Mr. Mocock, of Southwark, with a premium of 20 guineas, for his contrivance to prevent a jack from taking a retrograde courſe whenever the weight by any accidental circumſtance overbalances the power. The improved jack only differs from thoſe in common uſe in this reſpect, that it has a pall or clock, and ratchet, applied in ſuch manner as to ſtop the motion of the machine as ſoon as it begins to run back again. As the difference in the mechaniſm is very trifling, the improvement may be eaſily applied to any common jacks already made.

Jack is alſo the name of a well-known engine in the kitchen, uſed for turning a ſpit. Here the weight is the power applied, acting by a ſet of pulleys; the friction of the parts, and the weight with which the ſpit is charged, are the forces to be overcome; and a ſteady uniform motion is maintained by means of a fly.

The common worm-jack is repreſented at fig. 2. pl. XII. ABC is the barrel round which the cord QR is wound: KL the main wheel, commonly containing 60 teeth. N the worm wheel of about 30 teeth, cut obliquely. LM the pinion, of about 15. O the worm or endleſs ſcrew, conſiſting of two ſpiral threads, making an angle of 60 or 70 degrees with its axis. X the ſtud, and Z the loop of the worm ſpindle. P a heavy wheel, or fly, connected with the ſpindle of the endleſs ſcrew to make the motion uniform. DG the ſtruck wheel fixed to the axis FD. S, S, S, are holes in the frame, by which it may be nailed to a board, and thence to any wall, the end D being permitted to paſs through it. HI the handle going upon the axis ET, to wind up the weight when it has run down. R is a box of fixed pulleys, and V a correſponding one of moveable pulleys carrying the weight. The axis ET is fixed in the barrel AC, which axis being hollow, both it and the barrel turn round upon the axis FD, which is fixed to the wheel KL, when it turns in the order BTA; but cannot turn the contrary way, by reaſon of a catch nailed to the end AB, which lays hold of the croſs-bars in the wheel LK.

The weight by means of the cord QR, in conſequence of its deſcent, carries about the barrel AB, which by the action of the catch carries the wheel KL, and this moves the pinion LM and wheel N, the latter moving the worm O and the fly P. Alſo the wheel LM carries the axis FD with the wheel DG, which carries the cord or chain that goes about the wheel or pulley at the head of the ſpit. But when the handle H gives motion to the axis in a contrary order to that given by the weight, the catch is depreſſed; ſo that although the barrel BC moves and winds the cord upon it, the wheel DG continues at reſt. The time which the jack will continue in motion depends upon the number of pulleys at R and V: and as theſe increaſe or decreaſe, ſo muſt the weight which communicates the motion, in order to perform the ſame work in the ſame time.

Smoke-JACK is an engine uſed for the ſame purpoſe as the common jack; and is ſo called from its being moved by means of the ſmoke, or rarefied air, aſcending the chimney, and ſtriking againſt the ſails of the horizontal wheel AB (plate XII. fig. 1.), which being inclined to the horizon, is moved about the axis of the wheel, together with the pinion C, which carries the wheels D and E; and E carries the chain F, which turns the ſpit. The wheel AB ſhould be placed in the narrow part of the chimney, where the motion of the ſmoke is ſwifteſt, and where alſo the greateſt part of it muſt ſtrike upon the ſails.—The force of this machine depends upon the draught of the chimney, and the ſtrength of the fire.

Smoke-jacks are ſometimes moved by means of ſpiral flyers coiling about a vertical axle; and at other times by a vertical wheel with ſails like the float-boards of a mill: but the above is the more cuſtomary conſtruction.

JOINT, universal. See the introductory part of this volume.

KNEADING-MILL, is a contrivance by which large quantities of flour may be mixed and incorporated into dough.

In many places bakers follow the diſguſting practice of kneading the dough with their bare feet: and in others the buſineſs is effected by a wooden implement, being a lever; which, faſtened at one end by a moveable hinge, is worked up and down ſo as to preſs and knead the dough. But the machine we are about to deſcribe is far preferable, as it will knead the dough very completely, with a great ſaving of time and labour. It is uſed at the public baking-houſes of Genoa, and was firſt deſcribed in the *Atti della Societa Patriotica di Milano*, vol. II.

A, in fig. 4. pl. XVIII. is a frame of wood which ſupports the axis of the machine: a wall 14 palms high from the ground may be made uſe of inſtead of this frame. B a wall, three palms and a half thick, through which the aforeſaid axis paſſes. C another wall ſimilar to the former, and facing it, at the diſtance of 21 palms. D, the axis, thirty palms in length, and one palm and one-third in thickneſs. E the great wheel, fixed to the ſaid axis, between the frame and the wall; its diameter is 28 palms; and its breadth, which is capable of holding two men occaſionally, is five palms. F, are ſteps, by treading on which the men turn the wheel very ſmartly; they are two palms diſtant from each other, and one third of a palm in height. G, a ſmall wheel with cogs, fixed almoſt at the further extremity of the axis: its diameter is $12\frac{1}{2}$ palms. H a beam of wood which extends from one wall to the other; being 21 palms in length, and one and a third in thickneſs. A ſimilar beam, not ſeen in the figure, is on the oppoſite ſide of the axis. I, a tranſverſe piece of wood, placed near the wall C; it is fixed into the two beams, and ſerves to ſupport the further extremity of the axis: its length is 14 palms, and its thickneſs one and a third: there is likewiſe a tranſverſe piece (which cannot be ſeen in the figure) 14 palms long, and half a palm thick, placed cloſe to the wall B. K is a ſtrong curved piece of oak, fixed tranſverſely in the ſidebeams H, to receive the axis of the trundle: its length is 14 palms, and its thickneſs $1\frac{1}{2}$. L is a trundle of $5\frac{1}{2}$ palms in diameter, and $1\frac{1}{4}$ in height, which is moved by the cogged-wheel G. M is an axis proceeding from the trundle L, and continued through the croſs N to the bottom of the tub P; its centre is made of iron, partly ſquare and partly round, and it turns in a ſocket of braſs. The firſt part of this axis between the trundle L and the croſs N is of ſquare iron, ſurrounded by 2 pieces of wood, held together by iron hoops, which may be removed at pleaſure to examine the iron within: its length is 3 palms, its diameter about 1 palm. The ſecond part of the axis which is within the tube, is made like the firſt part: its height is $1\frac{1}{2}$ palm, its diameter $1\frac{1}{8}$. The wooden ſheath of this part of the axis is fixed to the bottom of the tub, by means of three ſcrews with their nuts. This axis is diſtant one-third of a palm from the neareſt triangular *beater* of the croſs. N the croſs, formed of two bars of wood unequally divided, ſo that the four arms of the croſs are of different lengths: one of the two pieces of wood of which the croſs is made, is 6 palms in length, the other 5: their thickneſs is $\frac{7}{12}$ of a palm, and their breadth 1 palm. O, four pieces of wood, called *beaters*, of a triangular ſhape, fixed vertically into the extremities of, and underneath, the arms of the fore-mentioned croſs: they are $1\frac{3}{4}$ palm in length, and half a palm in thickneſs; and beat or knead the dough in the tub at unequal diſtances from the centre. P is a ſtout wooden tub, about a quarter of a palm thick, well hooped with iron: its diameter is 6 palms, its height $1\frac{1}{2}$ in the clear.

Fig. 5. is a box or trough of wood, 4 palms long, and 3 wide, in which the leaven is formed (in about an hour) in a ſtove, and in which it is afterwards carried to the tub P.

Fig. 6. exhibits a view of the trundle, croſs, &c. with a ſection of the tub.

Fig. 7. is a bird's-eye view of the croſs and tub, with the upper ends of the triangular beaters.

This tub, P, will contain 18 rubbi (about 19 buſhels) of flour, which is carried to it in barrels: the leaven is then carried to it in the box or trough, fig. 5. and when the whole is tempered with a proper quantity of warm water, the men work in the wheel till the dough is properly and completely kneaded. In general a quarter of an hour is ſufficient to make very good dough; but an experienced baker who ſuperintends, determines that the operation ſhall be continued a few minutes more or leſs, according to circumſtances.

The meaſures in the preceding deſcription are given in Genoeſe palms, each of which is very nearly equal to 9·85 of our inches. The machinery may be varied in its conſtruction according to circumſtances, and the energy of the firſt mover much better applied than by men walking in a common wheel.

LATHE, a very uſeful engine for the turning of wood, ivory, metals, and other materials. The invention of the lathe is very ancient: Diodorus Siculus ſays, the firſt who uſed it was a grandſon of Dædalus, named Talus. Pliny aſcribes it to Theodore of Samos; and mentions one Thericles, who rendered himſelf very famous by his dexterity in managing the lathe. With this inſtrument the ancients turned all kinds of vaſes, many whereof they enriched with figures and ornaments in baſſo relievo. Thus Virgil: "*Lenta quibus torno facili ſuperaddita vitis.*"

The Greek and Latin authors make frequent mention of the lathe; and Cicero calls the workmen who uſed it *vaſcularii.* It was a proverb among the ancients, to ſay a thing was formed in the lathe, to expreſs its delicacy and juſtneſs.

The common lathe is compoſed of two wooden cheeks or ſides, parallel to the horizon, having a groove or opening between: perpendicular to theſe are two other pieces called *puppets,* made to ſlide between the cheeks, and to be fixed down at any point at pleaſure. Theſe have two points, between which the piece to be turned is ſuſtained: the piece is turned round backwards and forwards by means of a ſtring put round it, and faſtened above to the end of a pliable pole, and underneath to a tredle or board moved with the foot. There is alſo a reſt which bears up the tool, and keeps it ſteady. But the moſt ingenious lathes now conſtructed are different from the above: we ſhall deſcribe them under the article TURNING.

LENS GRINDING MACHINES, have been invented of many different kinds; but, ſince it has been admitted that, on the whole, ſpherical lenſes are the moſt practically uſeful, the conſtruction of lens-grinders has become comparatively ſimple. One of the beſt we have ſeen was invented by Mr. *Sam. Jenkins,* and deſcribed in No. 459. vol. xli. of the *Phil. Tranſac.* It is contrived to turn a ſphere at one and the ſame time on two axes, cutting each other at right angles, and will produce the ſegment of a true ſphere merely by turning round the wheels, without any care or ſkill of the workmen. A (fig. 1. pl. XX.) is a globe covered with cement, in which are fixed the pieces of glaſs to be ground: this globe is faſtened to the axis, and turns with the wheel B. C is the braſs cup which poliſhes the glaſs: this is faſtened to the axis, and turns with the wheel D. The motion of the cup C, therefore, is at right angles to the motion of the globe A; whence it follows, demonſtrably, that the pieces of glaſs ground by this double motion, muſt be formed into the ſegments of ſpheres.

The LEVER, treated as one of the mechanical powers, fell under our notice in book I. ch. iii. vol. I. where the theory of the various kinds of levers, whether ſtraight or bent, was laid down. Our preſent object is to deſcribe a combination of the lever with the axis in peritrochio, by means of which the reciprocating motion of the lever is made uſeful in giving a continued rectilinear motion to a heavy body, without changing the ſituation of the fulcrum of the lever. This contrivance is deſcribed by Belidor (Archit. Hydraul. tom. I.) under the name of *le levier de la Garouſſe*, and is generally called in England the *univerſal lever*. FGH (fig. 2. pl. XX.) is a ſtraight lever, whoſe centre of motion is G: on its extremity F, hang two bars FD, FE, the former of which has a hook to catch into the teeth of the wheel ACD, and the latter has its end ſlightly bent, ſo as to ſlide over the outer parts of thoſe teeth. The axle A has a cord wound about it, to the lower end of which is attached the weight W. Now ſuppoſe the end H of the lever raiſed from H by I, while the other end deſcends from F to B; the bar FE will then puſh the point E of the wheel from E to C, while the hook D ſlides over an equal ſpace on the other ſide of the wheel. After this, on the end H of the lever being brought down again by I to H, the end F aſcends through BF, and the hook D raiſes up the left hand ſide of the wheel through a ſpace equal to EC. Thus the reciprocating motion of the lever is made to communicate a continued rotatory motion to the wheel, and conſequently to raiſe the weight W ſuſpended from its axle by the cord. Here the advantage gained, neglecting friction and the ſtiffneſs of the cord, will be in the ratio compounded of the ratio of HG to GF, and the ratio of the radius of the wheel to that of the axle. Thus if HG were 10 times GF, and the radius of the wheel 10 times that of the axle, the power would then be to the weight raiſed nearly as 1 to 100.

This machine has been advantageouſly applied in drawing heavy loads along a plane nearly horizontal: in that caſe, the cord has been carried from A in nearly an horizontal direction, paſſed round a pulley *p*, attached to the load *w* or its carriage, and its end fixed to a poſt as at *a*, or perhaps to the frame of the wheel and axle. The pulley, it is obvious. almoſt doubles the advantage of the power; and ſince the force to be overcome when once the ſyſtem is put in motion is not equivalent to the whole load *w*, but merely to the friction, and the rigidity of the rope, a very great weight may be moved in this manner by a comparatively ſmall power. If the lever have another arm to the left of G (as it appears in the figure) equal to GH, a man may then work at each end, either by preſſing upon it or by pulling downwards with a cord; and thus the labourers will alternately relieve each other. Sometimes a heart-wheel has been combined with this univerſal lever: but it is not, we think, a combination to be recommended in practice.

If the centre of motion G were vertically above the centre of the wheel, and if another bar and hook ſimilar and equal in length to FD hung from the point *f*, *f* G being equal to GF; theſe two hooks would then catch alternately into the teeth on the riſing ſide of the wheel, and thus produce the continual rotatory motion: but this conſtruction has a practical diſadvantage; for when both bars work on the ſame ſide of the wheel, they will be in great danger of catching together and impeding each other's motions.

Univerſal levers have long been introduced into ſaw-mills, for the purpoſe of drawing along the logs to be ſawn. See SAW-MILL, alſo PIPE-BORER.

LINT-MILL. See FLAX-MILL.

LOADING AND UNLOADING MACHINE, an invention of Mr. G. Davis, of Windſor, for the purpoſe of removing ponderous ſubſtances to or from waggons, &c. with ſafety and convenience. This portable machine is repreſented in fig. 6. pl. XV. where A is the winch turning the bar B, on which are two endleſs ſcrews, or worms, CC, that work in the toothed wheels DD. Theſe wheels are fixed to the barrels EE, round which the ropes FF coil, wind up, or let out the ſame occaſionally: the ropes paſs over the pulleys GG; are brought round; and their ends, being furniſhed with hooks for that purpoſe, are hitched into ſtaples fixed to the front of the cart, or other carriage. Within theſe ropes, the load H is placed on a common ſtep-ladder I, that forms an inclined plane, up which, by turning the winch, the ropes are wound upon the barrels; and thus the load is raiſed into the carriage.

KK, the frame, intended to ſhew the part of the cart, or other carriage, on which the machine is to be occaſionally placed.

The whole of the barrels and cogged wheels are contained in an iron box L; the ſides of which are repreſented in the plate, as taken off, in order that the arrangement of the different parts may be better conceived.

The pulleys on the ſtage (GG) may, in moſt caſes, be affixed to the machine itſelf; which is adapted to every direction, and will ſuit carriages of every conſtruction.

The model correſponding to the preſent engraving is made on the ſcale of about four inches to a foot; and the inventor ſtates, that it will raiſe upwards of five cwt.—He is therefore confident, that his machine, when conſtructed of its intended ſize, will be capable of loading a ton weight by *one man only;* and that, even upon this enlarged plan, it does not exceed 112lb. in weight.

The Society of Arts in 1797 awarded 40 guineas to Mr. Davis, for this uſeful invention.

LOCK, a well-known inſtrument uſed for faſtening doors, cheſts, &c. generally opened by a key. The lock is reckoned the maſter-piece in ſmithery; a great deal of art and delicacy being required in contriving and varying the wards, ſprings, bolts, &c. and adjuſting them to the places where they are to be uſed, and to the ſeveral occaſions of uſing them. From the various ſtructure of locks, accommodated to their different intentions, they acquire various names. Thoſe placed on outer doors are called *ſtock locks;* thoſe on chamber-doors, *ſpring-locks;* thoſe on trunks, *trunk-locks*, *padlocks*, &c.—Of theſe the ſpring-lock is the moſt conſiderable, both for its frequency and the curioſity of its ſtructure. Its principal parts are, the main-plate, the cover-plate, and the pin-hole: to the main-plate belong the key-hole, top-hook, croſs-wards, bolt-toe or bolt-knab, drawback-ſpring tumbler, pin of the tumbler, and the ſtaples; to the cover-plate belong the pin, main-ward, croſs-ward, ſtep-ward or dap-ward; to the pin-hole belong the hook-ward, main croſs-ward, ſhank, the pot or bread, bow-ward, and bit.

The principle on which all locks depend is the application of a lever to an interior bolt, by means of a communication from without; ſo that, by means of the latter, the lever acts upon the bolt, and moves it in ſuch a manner as to ſecure the lid or door from being opened by any pull or puſh from without. The ſecurity of locks in general therefore depends on the number of impediments we can interpoſe betwixt the lever (the key) and the bolt which ſecures the door; and theſe impediments are well known by the name of *wards*, the number and intricacy of which alone are ſuppoſed to diſtinguiſh a good lock from a bad one. If theſe wards, however, do not in an effectual manner preclude the acceſs of *all* other inſtruments beſides the proper key, it is ſtill poſſible for a mechanic of equal ſkill with the lock-maker to open it without the key, and thus to elude the labour of the other.

The excellence of locks conſiſts in the ſecurity they afford; and as numberleſs ſchemes are continually brought forward by deſigning men, to elude every contrivance of the moſt ingenious mechanics, the invention of a durable lock, ſo conſtructed as to render it impoſſible for any perſon to open it without its proper key, has ever been an object of conſiderable importance.

In the year 1784 the *Society for the Encouragement of Arts*, &c. conferred their ſilver medal on Mr. Taylor, of Petworth, for his improvement on the latch or ſpring-bolts of common locks. This is effected by ſimply reverſing the tumbler, ſo that its curved ſide acts againſt two ſtubs fixed on the tail of the latch, and thruſts back the latter with eaſe; whether the knob be turned to the right or to the left, when the lock is opened. Mr. Taylor has alſo, behind the tail of the latch, fixed a guide containing a groove, in which runs a ſmall *friction-wheel*, that ſerves to keep the latch in its direct ſituation, and at the ſame time to diminiſh its friction: the arms of his tumbler are ſomewhat contracted, in order that the latch or ſpring-bolt may move with greater facility. By this conſtruction, the parts of the tumbler and latch, which are in contact, move in a line, ſo that they paſs over the greateſt ſpace, under the ſmalleſt angle; and the lock itſelf may be conſtantly uſed for ſeveral years, without requiring the application of oil.

Various patents have been obtained for the conſtruction of locks, ſo as to prevent the poſſibility of picking them: the principal of theſe is Mr. Bramah's, regiſtered in 1784; and Mr. Spears's, in 1795: but as the account of thoſe inventions would be unintelligible without the aid of ſeveral engravings, the curious reader will conſult the 5th and 8th vols. of the *Repertory of Arts and Manufactures*, where they are minutely ſpecified.

MANGLE, a valuable domeſtic machine, employed for the purpoſe of ſmoothing ſuch linen as cannot be conveniently *ironed*.

Various patents have been granted for improvements in this machinery; but, as they are not expired, and too complicated to be underſtood without very tedious details, we have annexed the figures in pl. XII. repreſenting an improved mangle contrived by Mr. Jee, of Rotherham; to whom the Society for the Encouragement of Arts, &c. in 1798, voted their ſilver medal, for the ingenuity diſplayed on that occaſion.

The following is a deſcription of Mr. Jee's improved mangle:

A (fig. 5.) points out the great wheel, which, in machines of a full ſize, is 15 inches in diameter. B, the arbor, on which the nut, C, is fixed. D, the handle of the winch. E, the crank, 21 inches in length. F, the rod of the crank. GG, repreſents the hollow ſtuds, by which the ends of the bed are lifted up. HH, the levers. IIII. the four pulleys fixed on the moveable bed K. LL, the ends of the rollers.

Fig. 6. repreſents a front view of one of the hollow ſtuds G, to ſhew its form, when ſtanding at the end of the bed; and into which the levers enter alternately, as often as it becomes neceſſary to elevate the bed, in order to put in, or take out, the rollers.

Mr. Jee's mangle is ſo conſtructed, that the handle requires to be turned one way only, in conſequence of which the machine moves with greater facility, and with incomparably leſs injury to the linen, than by varying the turnings, and in a manner cutting the different folds. Beſides, it poſſeſſes the great advantage, that a woman and one boy are ſufficient to work it, and can perform as much labour in the ſame period of time as three or four perſons with mangles of the common conſtruction.

The machine at MARLY, being ſo much celebrated, on account of its magnificence and the multiplicity of its parts, we ſhall here give ſome account of it, with a few remarks upon its conſtruction.

This machine, which was erected by one *Rannequin*, of the country of Liege, and began to work in 1682, is ſituated between Marly and the village *de la Chauſsée*: in that place the river is barred up, partly by the machine and partly by a dam which keeps up the water; but that the navigation may not be interrupted, two leagues above Marly a canal has been cut for the paſſage of boats and barges: there has alſo been erected (about 30 fathoms from the machine) a contrivance called an *ice-breaker*, to prevent floating pieces of ice or timber which come down the ſtream from damaging the machine; and the better to ſecure the penſtocks and the channels in which the wheels move, there is a grate of timber to ſtop whatever may come through the ice-breaker.

The water is raiſed to its deſtined height by means of 14 wheels which ſerve to work the pumps, by three different ſtages: firſt, from the river to a reſervoir, at the elevation of 160 Engliſh feet above the level of the Seine; then to a ſecond reſervoir, 346 feet higher; and from the latter to the ſummit of a tower rather more than 533 feet above the river.

The breadth of the machine comprehends 14 gets, or water-courſes, ſhut by ſluices or penſtocks, which are raiſed and depreſſed by racks; and in each of theſe gets is placed a wheel:

theſe wheels are diſpoſed on three lines; in the firſt, on the ſide which points up the ſtream there are ſeven, ſix in the ſecond, and only one in the third.

The ends of the axle of each wheel go beyond their bearing pieces, and are bent into a crank, which makes a lever of two feet; and it is to be obſerved, that the crank which is towards the mountain ſucks and lifts up the water of the river, to drive it into the firſt ciſtern, and the other crank gives motion to the balances.

Six of the wheels on the firſt line give motion by one of their cranks to an engine of eight pumps, without reckoning the feeder: theſe engines are compounded of a regulator, at each end of which hangs a ſquare piece of wood, that carries and directs four piſtons; the regulator is put in motion by two beams or leaders, one of which lying along anſwers to the crank of the wheel and a vertical regulator, and the other hanging down is united to the ſame regulator and to the balance.

Of the ſix wheels we have mentioned, there are five which by their other crank give motion to the pumps that work in the ciſtern of the firſt lift, by means of horizontal levers and chains that communicate the motion. The ſixth wheel, which is the firſt towards the dam, moves a long chain that works the pumps of one of the wells of the upper ciſtern, which is called the ciſtern of the great *chevalets*. Each of the cranks of the ſeventh wheel of the firſt line moves a chain which goes to the firſt ciſtern.

The ſix wheels of the ſecond line move, by each of their cranks, a chain that goes to the upper ciſtern, which (reckoning the chain that comes from the ſixth wheel of the firſt line) makes 13 chains. Theſe chains go over one of the ciſterns of the firſt lift; and five of them at the ſame time give motion to the piſtons of thirty pumps, whilſt the other chains go on ſtraight to the upper ciſtern.

Laſtly, the wheel which is on the third line, by each of its cranks, works an engine of eight ſucking and lifting pumps, and of itſelf ſupplies one conduit pipe.

The ſeven chains of the wheels of the firſt line in going along work alſo eight ſucking pumps placed a little below the ciſtern of the firſt lift, becauſe in that place there are the waters of a conſiderable ſpring brought thither by an aqueduct; and theſe ſame chains take up that water the ſecond time to force it by 49 pumps into the upper reſervoir, through two conduit pipes of eight inches, and three others of ſix inches diameter. The thirty pumps of the ciſtern of the firſt lift drive their water alſo through two pipes of eight inches diameter, which carry it into the upper ciſtern.

The water raiſed at the two ciſterns in the way up the hill diſcharges itſelf into a great reſervoir, and thence, by two conduit pipes of a foot diameter each, it runs into reſervoirs of communication to be diſtributed into the ſeveral wells or little ciſterns of the upper ciſtern, whence it is raiſed by 82 pumps, through 6 conduit pipes of 8 inches diameter, up into the tower which anſwers to the aqueduct.

The eight great chains that go ſtraight to the upper ciſtern, without moving any engines by the way, work 16 pumps behind the upper ciſtern, to bring back into the reſervoir of the ſaid ciſtern the water which is loſt out of the ſix pipes that go to the tower.

The eight engines which ſuck and lift the water from the river contain 64 pumps: the two ciſterns in the way up the hill together contain 79 pumps, and the upper ciſterns 82, to which adding the ſucking pumps called feeders, and the 8 others which are below the midway ciſtern, and beſides the 16 pumps which we mentioned as placed behind the upper ciſtern, the machine has in all 253 pumps.

The baſin of the tower which receives the water raiſed from the river, and ſupplies the aqueduct, is 610 fathoms diſtant from the river. The water having run along an aqueduct of 36 arches is ſeparated into different conduits which lead it to Marly, and formerly conveyed it alſo to Verſailles and Trianon.

Such is the mechaniſm of the machine of Marly. Its mean produce is from 30000 to 40000 gallons of water per hour. We ſay *mean* produce, becauſe, under certain favourable circumſtances, it raiſes more than 60000 gallons per hour. But during inundations, or when the Seine is frozen, when the water is very low, or when any repairs are making, the machine ſtops in great meaſure, if not entirely.

The annual expence of the machine, including the ſalaries of thoſe who ſuperintend it, and the wages of the workmen employed, together with repairs, neceſſary articles, &c. may amount to about 3300*l.* ſterling, or 9*l.* per day: which makes about 1 farthing for 90 gallons. Or, taking into the account the intereſt of 333000*l.* the original expence of erection, 90 gallons will coſt three halfpence, which is at the rate of a farthing for 15 gallons *.

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* This is very far from the price which the king of Denmark thought he might ſet on this water; for that prince, when he viſited Marly in 1769, being aſtoniſhed at the immenſe magnitude of the machine, the multiplicity of its movements, and the number of workmen it employed, conjectured that the water probably coſt as much as wine.

Whoever has an opportunity of examining this machine, or peruſes attentively the minute account of it given by Belidor in his ſecond volume, will be convinced that *Rannequin* was an ingenious practical machanic, but no mathematician or philoſopher. In ſeveral poſitions the moving forces act unneceſſarily obliquely, which occaſions a great loſs of power, and renders the machine leſs effectual. About $\frac{19}{20}$ of the whole moving power of ſome of the water-wheels are employed in giving a reciprocating motion to a ſet of rods and chains, which extend from the wheels to the ciſtern nearly three-fourths of a mile diſtant, where they work a ſet of pumps. By ſuch injudicious conſtruction, this engine is no leſs a monument of ignorance than of magnificence.

It is probable Rannequin thought his moving force would not be ſufficient to raiſe the water to the height of 533 feet, at once; but this is not agreeble to theory: for a proper calculation would ſhew that the force of one crank is more than ſufficient to raiſe a cylinder of water of that altitude, and above 8 inches in diameter. To effect this with ſafety, however, the conſtruction of the machine muſt be varied in ſeveral reſpects. But even according to the preſent conſtruction, the water might be raiſed in one jet to the ſecond reſervoir. This is manifeſt from two experiments, one made in 1738, and the other in 1775. In the firſt M. Camus endeavoured to make the water riſe in one jet to the tower: his attempt was not attended with ſucceſs; but he made the water riſe to the *foot* of the tower, which is conſiderably higher than the ſecond reſervoir. During this experiment the machine was prodigiouſly ſtrained, and it was found neceſſary to ſecure ſome parts of it with chains. The object of the ſecond trial, made in 1775, was to raiſe the water only to the ſecond well. It indeed aſcended thither at different times, and in abundance: but the pipes were exceedingly ſtrained at the bottom, ſo that ſeveral of them burſt; and it was neceſſary to ſuſpend and recommence the experiment ſeveral times. This however aroſe from the age of the tubes and their want of ſtrength, a fault which might eaſily have been remedied. Hence, it reſults from this trial, that the chains which proceed from the river to the firſt well might be ſuppreſſed, together with the firſt well itſelf; and this perhaps is all that is to be expected without a complete change in the machinery.

MILL, properly denotes a machine for *grinding*, or pulveriſing ſubſtances, as corn, &c.; but, in a more general ſignification, is now applied to many machines whoſe action ariſes in great meaſure from a circular motion. Of theſe there are various kinds deſcribed in different parts of this volume, as *Bark-mill*, *Barker's* *mill, Flax-mill, Flour-mill, Foot-mill, Hand-mill, Kneading-mill, Oil-mill, Paper-mill, Saw-mill, Tide-mill, Water-mill, &c*

As a well-conſtructed, yet cheap, family-mill cannot but be highly uſeful in many parts of the country, we ſhall here preſent a deſcription of the *Family-mill and Bolter* of Mr. T. Ruſtall, of Purbrook-heath, near Portſmouth, who received a premium of 40 guineas from the Society of Arts for his invention*.

In pl. XX. fig. 4. A, is the handle of the mill; B, one of the mill-ſtones, which is about 30 inches in diameter. and 5 inches in thickneſs, moving with its axis C: D, is the other mill-ſtone, which, when in uſe, is ſtationary; but which may be placed near to, or at a diſtance from, the moveable ſtone B, by means of three ſcrews paſſing through the wooden block E, that ſupports one end of the axis C; after it has been put through a hole or perforation in the bed-ſtone. The grain likewiſe paſſes through this perforation from the hopper F, into the mill. F, repreſents the hopper, which is agitated by two iron pins on the axis C, that alternately raiſe the veſſel containing the grain, which again ſinks by its own weight. In conſequence of this motion the corn is conveyed through a ſpout that paſſes from ſuch hopper into the centre of the mill behind, and through the bedſtone D. G, a paddle, regulating the quantity of corn to be delivered to the mill; and, by raiſing or lowering which, a larger or ſmaller proportion of grain may be furniſhed: H, the receptacle for the flour, into which it falls from the mill-ſtones, when ground: I, repreſents one of the two wooden ſupporters on which the bedſtone, D, reſts. Theſe are ſcrewed to the block E, and likewiſe mortiſed into the lower frame-work of the mill at K, which is connected by means of the pins or wedges L, L, L, that admit the whole mill to be eaſily taken to pieces: M, a fly-wheel, placed at the furtheſt extremity of the axis C, and on which another handle may be occaſionally fixed; N, a ſmall rail, ſerving to keep the hopper in its place; the furtheſt part of ſuch hopper reſting on a ſmall pin, which admits of ſufficient motion for that veſſel, to ſhake forward the corn: O, a ſpur-rail, for ſtrengthening the frame-work of the mill; P, the front upright, that is mortiſed into the frame-work, and ſerves as a reſt for the end of the iron axis C, which is next to the handle. On each extremity of ſuch axis there is a ſhoulder, which keeps it ſteady in its place. Laſtly, there is a cloth-hood fixed to a broad wooden hoop, which is placed over the ſtones while working, to prevent the finer particles of flour from eſcaping.

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* Mr. Ruſtall engages to furniſh the whole apparatus, and deliver it free of carriage, in London, for the moderate price of *twenty guineas.*

Fig. 5. repreſents the bolter, with its front removed, in order to diſplay its interior ſtructure; the machine being 3 feet 10 inches in length, 19½ inches in breadth, and 18 inches in depth, A, is a moveable partition, ſliding about four feet backwards or forwards, from the centre of the box, upon two wooden ribs, which are fixed to the back and front of the box, and one of which is delineated at the letter B; C, the lid of the bolter, repreſented open; D, a ſlider, which is moveable in a groove made in the lid, by means of two handles on the back of ſuch lid; E, a forked iron, fixed in the ſlider D, and which, when the lid is ſhut, takes hold of the edge of the ſieve F, and moves it backwards and forwards on the wooden ribs B, according to the agitation of the ſlider; G, repreſents a fixed partition in the lower centre of the box, which it divides into two parts, in order to ſeparate the fine from the coarſe flour; from this partition the ſlider A moves each way about four inches, and thus affords room for working the ſieve: H, a board that is parallel to the bottom of the bolter, and forms part of the ſlider A; this board ſerves to prevent any of the ſifted matter from falling into the other partition: I, repreſents two of the back feet, which ſupport the bolter.

Fig. 6. of the plate above mentioned is a view of the top, or upper part, of the lid of the bolter; K, the ſlider that moves the lengthwiſe of the bolter; L, L the handles by which the ſlider is worked; M, a ſcrew, ſerving to hold the fork, which imparts motion to the ſieve.

Fig. 7. repreſents the forked iron, E, ſeparately from the lid.

Both the mill and bolter may be conſtructed at a moderate expence, and they occupy only a ſmall ſpace of ground. The former may even be worked in a public kitchen, or within a room in a farm-houſe, without occaſioning any great incumbrance.

The particular excellence of the mill conſiſts in this circumſtance, that, from the vertical poſition of its ſtones, it may be put in action without the intervention of cogs or wheels. It may be employed in the grinding of malt, the bruiſing of oats for horſes, and for making flour, or for all theſe purpoſes: it may likewiſe be eaſily altered, ſo as to grind either of theſe articles to a greater or leſs degree of fineneſs.

Another advantage peculiar to Mr. Ruſtall's contrivance is, that one man is ſufficient to work it; though, if two perſons, namely, a man and a boy, be employed, they will be able to produce, in the courſe of two hours, a quantity of flour ſufficient to ſerve a family, conſiſting of ſix or eight perſons, for a whole week:—repeated ſatisfactory trials have proved, that this mill grinds the corn completely, and at the rate of one buſhel of wheat within the hour. Beſides, the induſtrious farmer will thus be enabled to make comparative experiments on the quality of his grain, and may furniſh himſelf, at a trifling expence, with flour from his own wheat, without apprehending any adulteration; or without being expoſed to the impoſitions, or caprice, of fraudulent and avaricious millers.

Laſtly, though Mr. R.'s bolter be more particularly calculated for ſifting flour, it may alſo be applied to various other uſeful purpoſes, and eſpecially with a view to obviate the inconveniences neceſſarily attendant on the levigation of noxious ſubſtances, and to prevent the waſte of their finer particles.

The ſubject of mill-work has engaged the attention of many authors in different countries: the following is a catalogue of the chief writings, both theoretical and deſcriptive.

Künſtliche abriſs, allerhand waſſer- wind- roſs- und handmuhlen, &c. von *Jacob. de Strada à Roſberg.* 1617.

Georg Chriſtoph Luerner Machina toreutica nova; oder, beſchreibung der neu erfundenen Drehmühlen. 1661.

Theatrum machinarum novum; das iſt, neu vermehrter Schauplatz der mechaniſchen Künſte, handelt von allerhand waſſer- wind- roſs- gewicht- und hand- muhlen. Von *Geo. And. Bocklern.* 1661.

Contenta diſcurſus mechanici, concernentis deſcriptionem optimæ formæ velorum horizontalium pro uſu molarum, nec non fundamentum inclinatorum velorum in navibus, habita coram Societate Regia, a R. H. tranſlata ex collectionibus philoſophicis M. Dec. num. 3. pa. 61. 1681.

Diſſertatio hiſtorica de molis, quam præſide *Joh. Phil. Treuer* defend. *Jo. Tob. Mühlberger* Ratiſbonens. Jenae. 1695.

Martin Marten's Wilkundige beſchouwinge der wind—of wadermoolens, vergeleken met die van den heer *Johann Lulofs.* Amſterdam. 1700.

Vollſtändige mühlen-baukunſt, von *Leonhard Chriſtoph. Sturm.* 1718.

Jacob Leupold's Theatrum machinarum. 1724, 1725.

Remarques ſur les aubes ou pallettes des moulins, et autres machines mues par le courant des rivières. Par *M. Pitot*, mem. Acad. Roy. Paris. 1729.

Joh. van. Zyl theatrum machinarum univerſale of groot algemeen moolen-bock, &c. Amſterdam. 1734.

Jo. Carol. Totens Diſſer. de machinis molaribus optime conſtruendis. Lugd. Batav. 1734.

Kurze, aber deutliche anweiſung zur conſtruction der wind- und waſſer-muhlen, von *Gottfr. Kinderling.* 1735.

Deſaguliers's experimental philoſophy. 1735, 1744.

Architecture hydraulique, par *M Belidor.* 1737, 1753.

Part of a letter from Mr. W. Anderſon, F. R. S. to Mr. Baker, F. R. S. containing a deſcription of a water-wheel for mills invented by Mr. *Philip Williams.* Phil. Tranſ. vol. 44, 1746.

Leonh. Euleri, De conſtructione aptiſſima molarum alatarum diſp. Nov. Com. Acad. Petrop. tom. 4. 1752.

Mémoire dans lequel on démontre que l'eau d'une chûte deſtinée à faire mouvoir quelque machine, moulin ou autre, peut toujours produire beaucoup plus d'effét en agiſſant par ſon poids qu'en agiſſant par ſon choc, et que les roues à pots qui tournent lentement produiſent plus d'effet que celles qui tournent vîte, relativement aux chûtes et aux dépenſes. Par *M. de Parcieux,* Acad. Roy. Paris. 1754.

Jo. Alberti Euleri Enodatio queſtionis: quo modo vis aquæ aliuſve fluidi cum maximo lucro ad molas circumagendas, aliave opera perficienda impendi poſſit, præmio à ſocietate Regia. Sci. Gotting. 1754.

Recherches plus exactes ſur l'effet des moulins à vent, par *M. Euler.* Hiſt. Acad. Roy. Berlin. 1756.

An experimental enquiry concerning the natural powers of wind and water to turn mills and other machines depending on a circular motion. By Mr. *J. Smeaton,* F. R. S. Phil. Tranſ. 1759.

[Abſtracts of this and Mr. Smeaton's other papers on water and wind mills have been given in book iv. of our firſt volume, and the Introduction to this. They were collected and publiſhed by Taylor, Holborn, in 1794.]

Mémoire dans lequel on prouve que les aubes des roues mûes par les courans des grandes rivières ſeroient beaucoup plus d'effet ſi elles étoient inclinées aux rayons, qu'elles ne font étant appliquées contre les rayons mêmes, comme elles le font aux moulins pendans et aux moulins ſur bateaux qui ſont ſur les rivières de Seine, de Marne, de Loire, &c. Par *M. de Parcieux,* mem. Acad. Roy. Paris. 1759.

Joh. Albert Euler's Abhandlung von der bewegung ebener flächen, wenn ſie vom winde getrieben werden. 1765.

Schauplatz des mechaniſchen mühlenbaues, darinnen von verſchiedenen hand- trett- roſs- gewicht- waſſer- und wind-mühlen gehandelt wird, durch *Johann Georg Scopp* I. C. iter Theil. 1766.

Theatrum machinarum molarium, oder ſchauplatz der mühlenbaukunſt. als der neunte theil von des ſel hrn *Jac. Leupolds* theatro machinarum, von *Joh. Mathias Beyern.* 1767, 1788, 1802.

A memoir concerning the moſt advantageous conſtruction of water-wheels, &c. by Mr. *Mallet* of Geneva. Phil. Trans. 1767.

Mémoire ſur les roues hydrauliques, par M. le Chevalier *de Borda*, mem. Acad. Roy. Paris. 1767.

Kurzer unterricht, allerley arten von wind- und waſſer- mühlen auf die vortheilhafteſte weiſe zu erbauen, nebſt einigen gedanken über die verbeſſerung des räderwerks an den mühlen, von *Joh. König.* 1767.

G. G. Biſchoff's Beyträge zur matheſis der muhlen. 1767.

Sur la poſition des ailes des moulins à vent. *D'Alembert.* Opuſc. mathema. tom. 5. 1768.

Determination générale de l'effet des roues mûes par le choc de l'eau, par M l'abbé *Boſſut*, mem. Acad. Roy. Paris. 1769.

Andreas Kaovenhöfer, Deutliche abhandlung von den rädern der waſſermühlen, und von dem einrandigen werke der ſchneidemühlen. 1770.

Manuel du meûnier et du charpentier des moulins, redige par *Edm. Bequillet.* 1775.

Rémarques ſur les moulins à vent, par *M. Lambert.*

Rémarques ſur les moulins et autres machines, où l'eau tombe en deſſus de la roue, par *M. Lambert.*

Experiences et rémarques ſur les moulins que l'eau meut par en bas dans une direction horizontale, par *M. Lambert.*

Rémarques ſur les moulins et autres machines dont les roues prennant l'eau à une certaine hauteur, par *M. Lambert.*

[The laſt four articles are inſerted in Mem. Acad. Roy. Berlin. 1775.]

Of the degrees and quantities of winds requiſite to move the heavier kinds of wind-machines, by *John Stedmann*, M. D. Phil. Trans. 1777.

Ausführliche erklärung der vorſchläge für die längere dauer der muhlenwerke, nebſt ähnlichen gegenſtanden, in ein geſpräch verfaſſet, von *Johann Chriſtian Füllmann*, Mühlenmeiſter. 1780.

Obſervations théoriques et experimentales ſur l'effet des moulins à vent, et ſur la figure de leurs ailes, par *M. Coulumb*, mem. Acad. Roy. Paris. 1781.

Tratado de los granos y modo de molerlos con economia, de la conſervacion de aſtos y de las harinas; eſcr. en Fr. par M. *Beguillet*, y extract, y trad. al Caſt. con algun notas y un ſupplem, por *Ph. Mareſcaulchi.* Madrid. 1786.

Suite de l'architecture hydraulique, par *M. Fabrre*, 1786.

Mémoires ſur les moyens de perfectionner les moulins, et la mouture économique, par *C. Bucquet.* 1786.

Manuel ou vocabulaire des moulins à pot. A Amſt. 1786.

Die nothigſten kenntniſſe zur anlegung, beurtheilung und berechnung der waſſermühlen, und zwar der mahl- oehl- und säge- mühlen, ſür anfänger und liebhaber der mühlenbaukunſt, von *Joh. Chriſt. Huth.* 1787.

An eſſay proving iron far ſuperior to ſtone of any kind for breaking and grinding of corn, &c. by *W. Walton.* 1788.

Mühlenpraktik, oder unterricht in dem mahlen der brodfrüchte, für polizeybeamte, gaverkſleute und hauſwirthe, von *L. Ph. Hahn.* 1790.

The young millwright and miller's guide, by *Oliver Evans.* Philadelphia. 1790.

Manuel du meûnier et du conſtructeur des moulins à eau et à grains, par *C. Bucquet.* 1791.

Praktiſche anweiſung zum mühlenbau, von *Lr. Clauſen.* 1792.

Beſchreibung zweir maſchinen zur reinigung des korns, von *Lr. Clauſen.* 1792.

Inſtructions ſur l'uſage des moulins à bras, inventés et perfectionnés par les Citoyens *Durand* père et fils, mécaniciens. 1793.

Theoretiſch-praktiſche abhandlung über die beſſerung der muhlräder von dem verfaſſer der zweckmäſſigen luftreiniger, &c. 1795.

A treatiſe on mills, in four parts, by *John Banks.* 1795.

Handbuch der maſchinenlehre, ſur praktiker und akademiſche lehrer, von *Karl Chriſtian Langsdorf.* 1797, 1799.

On the power of machines: including Barker's-mill, Weſtgarth's engine, Cooper's-mill, horizontal water-wheel, &c. by *John Banks.* 1803.

The experienced millwright, by *Andrew Gray*, millwright. 1804.

The tranſactions of the Society of Arts and Manufactures; ſeveral of the volumes of which contain improvements in millwork. See alſo the Repertory of Arts, in ſeveral places.

MULLERS for grinding colours, according to the common conſtruction, are too well known and too ſimple to need a particular deſcription here. But Mr. James Rawlinſon, of Derby, has invented a *concave* muller, for which the Society of Arts preſented him a ſilver medal and ten guineas, on account of its ingenuity. He has uſed his machine for ſeveral years, and has found it much more effectual and expeditious in reducing the colour to extreme fineneſs than the uſual method, and much leſs injurious to the health of the workman, who frequently has done as much with it in three hours as he could in twelve with the muller and ſlab.

The machine conſiſts of a flat cylinder of black marble, ſixteen inches and a half diameter, and four and a half thickneſs, with an axle traverſing its centre (thus ſomewhat reſembling a common cutler's grindſtone). It is ſuſpended on a ſimilar frame, in a vertical poſition, and turned round in the ſame manner by a winch: a concave piece of marble is provided, of the ſame breadth as the circular ſtone, forming a ſegment of the ſame circle one third of the circumference in extent: this, which may be conſidered as the muller, is fitted into a piece of ſolid wood of ſimilar ſhape, one end of which is ſecured looſely by a hinge or otherwiſe to the frame; the other end, riſing over the circular ſtone and ſupported by it, is further preſſed down on it by a long ſpring bent over from the oppoſite extremity of the ſtand, and regulated as to its preſſure by a ſcrew, whoſe end turns againſt the concave muller: a ſlight frame of iron in front, moveable on a hinge, by which it is ſecured to the frame, ſupports a ſcraper, for taking off the colour, formed of a piece of watch-ſpring, which is turned back out of the way when not in uſe. Mr. R. thinks the circular grindſtones might be made much larger than that he uſed, to advantage, and that one of two feet diameter would not occaſion too much labour to one man to turn it: he computes that in his machine there are ſeventy ſquare inches of ſurface of the concave muller in conſtant work on the paint, while in the common muller not more than ſixteen ſquare inches are uſually in contact with the ſlab. The machine will be found equally ſerviceable for the colours ground in water as for thoſe prepared with oil, according to Mr. R., who highly recommends its uſe to all colourmen.

Mr. R. adviſes, in making up the colours in bladders, to inſert a bit of quill or reed in the neck of the bladder, which will thus bind better in tying; and, admitting of a ſecure ſtopper, will be more cleanly and leſs waſteful than the uſual method of ſtopping with a nail, and keep the colour more ſafe from the air. Retroſpect, &c. No. 1.

NORIA. See HYDRAULIC-*machines*, No. 3.

OIL-MILL, a mill for expreſſing the oils from fruits, or grains, &c. As theſe kingdoms do not produce the olive, it would be needleſs to deſcribe the mills which are employed in the ſouthern parts of Europe. We ſhall content ourſelves, therefore, with a deſcription of a Dutch oil-mill, employed for grinding and preſſing lint-ſeed, rape-ſeed, and other oleaginous grains. Further, to accommodate our deſcription ſtill more to our local circumſtances, we ſhall employ water as the firſt mover; thus avoiding the enormous expence and complication of a windmill.

In plate XXI. fig. A,

1. Is the elevation of a wheel, over or under-ſhot, as the ſituation may require.

2. The bell-metal ſocket, ſupported by maſonry, for receiving the outer gudgeon of the water-wheel.

3. The water-courſe.

Fig. B.

1. A ſpur-wheel upon the ſame axis, having 52 teeth.

2. The trundle that is driven by No. 1. and has 78 ſtaves.

3. The wallower, or axis for raiſing the peſtles. It is furniſhed round its circumference with wipers for lifting the peſtles, ſo that each may fall twice during one turn of the water-wheel, that is, three wipers for each peſtle.

4. A frame of timber, carrying a concave half-cylinder of bell-metal, in which the wallower (caſed in that part with iron plates) reſts and turns round.

5. Maſonry ſupporting the inner gudgeon of the water-wheel and the above-mentioned frame.

6. Gudgeon of the wallower, which bears againſt a bell-metal ſtep fixed in the wall. This double ſupport of the wallower is found to be neceſſary in all mills which drive a number of heavy ſtampers.

Fig. C, is the elevation of the peſtle and preſs-frame, their furniture, the mortars, and the preſs-peſtles.

1. The ſix peſtles.

2. Croſs pieces between the two rails of the frame, forming, with theſe rails, guides for the perpendicular motion of the peſtles.

3. The two rails. The back one is not ſeen. They are checked and bolted into the ſtandards No. 12.

4. The tails of the lifts, correſponding to the wipers upon the wallower. See the article Wiper.

5. Another rail in front, for carrying the detents which hold up the peſtles when not acting. It is marked 14 in fig. M.

6. A beam a little way behind the peſtles. To this are fixed the pulleys for the ropes which lift and ſtop the peſtles. It is repreſented by 16 in fig. M.

7. The ſaid pulleys with their ropes.

8. The driver, which ſtrikes the wedge that preſſes the oil.

9. The diſcharger, a ſtamper which ſtrikes upon the inverted wedge, and looſens the preſs.

10. The lower rail with its croſs pieces, forming the lower guides of the peſtles.

11. A ſmall cog-wheel upon the wallower, for turning the

ſpatula, which ſtirs about the oil-ſeed in the chauffer-pan. It has 28 teeth, and is marked No. 6. in fig. M.

12. The four ſtandards, mortiſed below into the block, and above into the joiſts and beams of the building.

13. The ſix mortars hollowed out of the block itſelf, and in ſhape pretty much like a kitchen pot.

14. The feet of the peſtles, rounded into cylinders, and ſhod with a great lump of iron.

15. A board behind the peſtles, ſtanding on its edge, but inclining a little backwards. There is ſuch another in front, but not repreſented here. Theſe form a ſort of trough, which prevents the ſeed from being ſcattered about by the fall of the peſtles, and loſt.

16. The firſt preſs-box (alſo hollowed out of the block), in which the grain is ſqueezed, after it has come for the firſt time from below the mill-ſtones.

17. The ſecond preſs-box, at the other end of the block, for ſqueezing the grain after it has paſſed a ſecond time under the peſtles.

18. Frame of timber for ſupporting the other end of the wallower, in the ſame manner as at No. 4. fig. B.

19. Small cog-wheel on the end of the wallower, for giving motion to the mill-ſtones. It has 28 teeth.

20. Gudgeon of the wallower, bearing on a bell-metal ſocket fixed in the wall.

21. Veſſels for receiving the oil from the preſs-boxes.

Fig. D. Elevation and mechaniſm of the mill-ſtones.

1. Upright ſhaft, carrying the great cog-wheel above, and the runner mill-ſtones below in their frame.

2. Cog-wheel of 76 cogs, driven by No. 19. of fig. C.

3. The frame of the runners.

4. The innermoſt runner, or the one neareſt the ſhaft.

5. Outermoſt ditto, being further from the ſhaft.

6. The inner rake, which collects the grain under the outer runner

7. The outer-rake, which collects the grain under the inner runner. In this manner the grain is always turned over and over, and cruſhed in every direction. The inner rake lays the grain in a ſlope, of which fig. O is a ſection; the runner flattens it, and the ſecond rake lifts it again, as is marked in fig. P; ſo that every ſide of a grain is preſented to the mill-ſtone, and the reſt of the legger or nether mill-ſtone is ſo ſwept by them, that not a ſingle grain is left on any part of it. The outer rake is alſo furniſhed with a rag of cloth, which rubs againſt the border or hoop that ſurrounds the nether mill-ſtone, ſo as to drag out the few grains which might otherwiſe remain in the corner.

8. The ends of the iron axle which paſſes through the upright ſhaft, and through the two runners. Thus they have two motions: 1mo, A rotation round their own axis; 2do, That by which they are carried round upon the nether mill-ſtone on which they roll. The holes in theſe mill-ſtones are made a little wide; and the holes in the ears of the frame, which carry the ends of the iron axis, are made oval up and down. This great freedom of motion is neceſſary for the runner mill-ſtones, becauſe frequently more or leſs of the grain is below them at a time, and they muſt therefore be at liberty to get over it without ſtraining, and perhaps breaking, the ſhaft.

9. The ears of the frame which lead the two extremities of the iron axis. They are mortiſed into the under ſide of the bars of the ſquare frame, that is carried round with the ſhaft.

10. The border or hoop which ſurrounds the nether mill-ſtone.

11. and 12. The nether mill-ſtone, and maſonry which ſupports it.

Fig. K. Plan of the runner mill-ſtones, and the frame which carries them round.

1, 1. Are the two mill-ſtones.

3, 3, 3, 3. The outſide pieces of the frame.

4, 4, 4, 4. The croſs-bars of the frame which embrace the upright ſhaft 5, and give motion to the whole.

6, 6. The iron axis upon which the runners turn.

7. The outer rake.

8. The inner ditto.

Fig. L. Repreſents the nether mill-ſtone ſeen from above.

1. The wooden gutter, which ſurrounds the nether mill-ſtone.

2. The border or hoop, about ſix inches high, all round, to prevent any ſeed from being ſcattered.

3. An opening or trap-door in the gutter, which can be opened or ſhut at pleaſure. When open, it allows the bruiſed grain collected in and ſhoved along the gutter by the rakes to paſs through into troughs placed below to receive it.

4. Portion of the circle deſcribed by the outer runner.

5. Portion of the circle deſcribed by the inner one. By theſe we ſee that the two ſtones have different routes round the axis, and bruiſe more ſeed.

6. The outer rake.

7. The inner ditto.

8. The ſweep, making part of the inner rake, occaſionally let down for ſweeping off all the ſeed when it has been ſufficiently bruiſed. The preſſure and action of theſe rakes is adjuſted by means of wooden ſprings, which cannot be eaſily and diſtinctly repreſented by any figure. The oblique poſition of the rakes

(the outer point going foremoſt) cauſes them to ſhove the grain inwards or toward the centre, and at the ſame time to turn it over, ſomewhat in the ſame manner as the mould-board of a plough ſhoves the earth to the right hand, and partly turns it over. Some mills have but one ſweeper; and, indeed, there is great variety in the form and conſtruction of this part of the machinery.

Fig. M. Profile of the peſtle frame.

1. Section of the horizontal ſhaft.

2. Three wipers for lifting the peſtles. See Wiper.

3. Little wheel of 28 teeth, for giving motion to the ſpatula.

4. Another wheel, which is driven by it, having 20 teeth.

5. Horizontal axle of ditto.

6. Another wheel on the ſame axle, having 13 teeth.

7. A wheel upon the upper end of the ſpindle, having 12 teeth.

8. Two guides, in which the ſpindle turns freely, and ſo that it can be ſhifted higher and lower.

9. A lever, moveable round the piece No. 14. and having a hole in it at 9, through which the ſpindle paſſes, turning freely. The ſpindle has in this place a ſhoulder, which reſts on the border of the hole 9; ſo that by the motion of this lever the ſpindle may be diſengaged from the wheel-work at pleaſure. This motion is given to it by means of the lever 10, 10, moveable round its middle. The workman employed at the chauffer pulls at the rope 10, 11, and thus diſengages the ſpindle and ſpatula.

11. A peſtle ſeen ſidewiſe.

12. The lift of ditto.

13. The upper rails, marked No. 3. in fig. C.

14. The rail, marked No. 5.' in fig. C. To this are fixed the detents, which ſerve to ſtop and hold up the peſtles.

15. A detent, which is moved by the rope at its outer end.

16. A bracket behind the peſtles, having a pulley, through which paſſes the rope going to the detent 15.

17. The ſaid pulley.

18. The rope at the workman's hand, paſſing through the pulley 17, and fixed to the end of the detent 15.

This detent naturally hangs perpendicular by its own weight. When the workman wants to ſtop a peſtle, he pulls at the rope 18, during the riſe of the peſtle. When this is at its greateſt height, the detent is horizontal, and prevents the peſtle from falling by means of a pin projecting from the ſide of the peſtle, which reſts upon the detent, the detent itſelf being held in that poſition by hitching the loop of the rope upon a pin at the workman's hand.

19. The two lower rails, marked No. 10. fig. C.

20. Great wooden, and ſometimes ſtone, block, in which the mortars are formed, marked No. 21. in fig. C.

21. Veſſel placed below the preſs-boxes for receiving the oil.

22. Chauffer, or little furnace, for warming the bruiſed grain.

23. Backet in the front of the chauffer, tapering downwards, and opening below in a narrow ſlit. The hair bags, in which the grain is to be preſſed after it has been warmed in the chauffer, are filled by placing them in this backet. The grain is lifted out of the chauffer with a ladle, and put into theſe bags; and a good quantity of oil runs from it through the ſlit at the bottom into a veſſel ſet to receive it.

24. The ſpatula attached to the lower end of the ſpindle, and turning round among the grain in the chauffer-pan; thus preventing it from ſticking to the bottom or ſides, and getting too much heat.

The firſt part of the proceſs at an oil-mill is bruiſing the ſeed under the runner ſtones*. That this may be more expeditiouſly done, one of the runners is ſet about ⅔ds of its own thickneſs nearer the ſhaft than the other. Thus they have different treads; and the grain, which is a little heaped towards the centre, is thus bruiſed by both. The inner rake gathers it up under the outer ſtone into a ridge, of which the ſection is repreſented in plate XXI. fig. O. The ſtone paſſes over it and flattens it. It is gathered up again into a ridge, of the form of fig. P, under the inner ſtone, by the outer rake, which conſiſts of two parts. The outer part preſſes cloſe on the wooden border which ſurrounds the nether ſtone, and ſhoves the ſeed obliquely inwards, while the inner part of this rake gathers up what had ſpread toward the centre. The other rake has a joint near the middle of its length, by which the outer half of it can be raiſed from the nether ſtone, while the inner half continues preſſing on it, and thus ſcrapes off the moiſt paſte. When the ſeed is ſufficiently bruiſed, the miller lets down the outer end of the rake. This immediately gathers the whole paſte, and ſhoves it obliquely outwards to the wooden rim, where it is at laſt brought to a part that is left unboarded, and it falls through into troughs placed to receive it. Theſe troughs have holes in the bottom, through which the oil drips all the time of the operation. This part of the oil is directed into a particular ciſtern, being conſidered as the pureſt of the whole; having been obtained, without preſſure, by the mere breaking of the hull of the ſeed.

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* We are told, that in a mill at Reichenhoffen, in Alſace, a conſiderable improvement has been made by paſſing the ſeed between two ſmall iron rollers, before it is put under the mill-ſtones. A great deal of work is ſaid to be ſaved by this preliminary operation, and finer oil produced: which we think very probable. The ſtamping and preſſing go on as in other mills.

In ſome mills this operation is expedited, and a much greater quantity of this beſt oil is obtained, by having the bed of maſonry which ſupports the legger formed into a little furnace, and gently heated. But the utmoſt care is neceſſary to prevent the heat from becoming conſiderable. This, enabling the oil to diſſolve more of the fermentable ſubſtance of the ſeed, expoſes the oil to the riſk of growing ſoon very rancid; and, in general, it is thought a hazardous practice, and the oil does not bring ſo high a price.

When the paſte comes from under the ſtones it is put into the hair bags, and ſubjected to the firſt preſſing. The oil thus obtained is alſo eſteemed as of the firſt quality, ſcarcely inferior to the former; and is kept apart: (the great oil ciſtern being divided into ſeveral portions by partitions).

The oil cakes of this preſſing are taken out of the bags, broken to pieces, and put into the mortars for the firſt ſtamping. Here the paſte is again broken down, and the parenchyma of the ſeed reduced to a fine meal. Thus free egreſs is allowed to the oil from every veſicle in which it is contained. But it is now rendered much more clammy, by the forcible mixture of the mucilage, and even of the finer parts of the meal. When ſufficiently pounded, the workman ſtops the peſtle of a mortar, when at the top of its lift, and carries the contents of the mortar to the firſt chauffer pan, where it is heated to about the temperature of melting bees-wax (this, we are told, is the teſt), and all the while ſtirred about by the ſpatula. From thence it is again put into hair bags, in the manner already deſcribed; and the oil which drips from it during this operation is conſidered as the beſt of the ſecond quality, and in ſome mills is kept apart. The paſte is now ſubjected to the ſecond preſſing, and the oil is that of the ſecond quality.

All this operation of pounding and heating is performed by one workman, who has conſtant employment by taking the four mortars in ſucceſſion. The putting into the bags and conducting of the preſſing gives equal employment to another workman.

In the mills of Picardy, Alſace, and moſt of Flanders, the operation ends here; and the produce from the chauffer is increaſed, by putting a ſpoonful or two of water into the pan among the paſte.

But the Dutch take more pains. They add no water to the paſte of this their firſt ſtamping. They ſay that this greatly lowers the quality of the oil. The cakes which reſult from this preſſing, and are there ſold as food for cattle, are ſtill fat and ſoftiſh. The Dutch break them down, and ſubject them to the peſtles for the ſecond ſtamping. Theſe reduce them to an impalpable paſte, ſtiff like clay. It is lifted out, and put into the ſecond chauffer pan; a few ſpoonfuls of water are added, and the whole kept for ſome time as hot as boiling water, and carefully ſtirred all the while. From thence it is lifted into the hair bags of the laſt preſs, ſubjected to the preſs; and a quantity of oil, of the loweſt quality, is obtained, ſufficient for giving a ſatisfactory profit to the miller. The cake is now perfectly dry, and hard, like a piece of board, and is ſold to the farmers. Nay, there are ſmall mills in Holland which have no other employment than extracting oil from the cakes which they purchaſe from the French and Brabanters; a clear indication of the ſuperiority of the Dutch practice.

The nicety with which that induſtrious people conduct all their buſineſs is remarkable in this manufacture.

In their oil ciſtern, the parenchymous part, which unavoidably gets through, in ſome degree, in every operation, gradually ſubſides; and the liquor, in any diviſion of the ciſtern, comes to conſiſt of ſtrata of different degrees of purity. The pumps which lift it out of each diviſion are in pairs; one takes it up from the very bottom, and the other only from half depth. The laſt only is barrelled up for the market, and the other goes into a deep and narrow ciſtern, where the dreg again ſubſides, and more pure oil of that quality is obtained. By ſuch careful and judicious practices, the Dutch not only ſupply themſelves with this important article, but annually ſend conſiderable quantities even into thoſe provinces of France and Flanders where they bought the ſeed from which it was extracted. When we reflect on the high price of labour in Holland, on the want of timber for machinery, on the expence of building in that country, and on the enormous expence of wind-mill machinery, both in the firſt erection and the ſubſequent wear and tear, it muſt be evident, that oil-mills erected in England on water falls, and after the Dutch manner, cannot fail of being a great national advantage. The chatellanie or ſeigneurie of Lille alone makes annually between 30,000 and 40,000 barrels, each containing about 26 gallons.

What is here delivered is only a ſketch. Every perſon acquainted with machinery will underſtand the general movements and operations. But the intelligent mechanic well knows, that operations of this kind have many minute circumſtances which cannot be deſcribed, and which, nevertheleſs, may have a great influence on the whole. The rakes in the bruiſing-mill have an office to perform which reſembles that of the hand, directed by a careful eye and unceaſing attention. Words cannot communicate a clear notion of this; and a mill, conſtructed from the beſt drawings, by the moſt ſkilful workman, may gather the feed ſo ill, that the half of it ſhall not be bruiſed after many rounds of the machinery. This produces a ſcanty return of the fineſt oil; and the mill gets a bad character. The proprietor loſes his money, is diſcouraged, and gives up the work.—There is no ſecurity but by procuring a Dutch millwright, and paying him with the liberality of Britons. Such unhoped-for taſks have been performed of late years by machinery; and mechanical knowledge and *invention* are now ſo generally diffuſed, that it is highly probable that we ſhould ſoon excel our teachers in this branch. But this very diffuſion of knowledge, by encouraging ſpeculation among the artiſts, makes it a ſtill greater riſk to erect a Dutch oil-mill without having a Dutchman, acquainted with its moſt improved preſent form, to conduct the work.—*Supp. Encycla. Britan.*

Boring of ORDNANCE. Till within a few years, iron ordnance were caſt with a cylindrical cavity, nearly of the dimenſions of the caliber of the piece, which was afterwards enlarged to the proper caliber by means of ſteel cutters fixed into the dog-head of a boring bar-iron. Three equidiſtant ſide-cutters were requiſite to preſerve the caliber ſtraight and cylindrical; and a ſingle cutter was uſed at the end of the bar to ſmooth the breech of the piece. In boring ordnance caſt hollow, the piece was fixed upon a carriage that could be moved backwards and forwards in a direct line with the centre of a water-wheel; in this centre was fixed the boring-bar, of a ſufficient length to reach up to the breech of the piece, or more properly to the further end of the caliber. The carriage with the piece being drawn backwards from the centre of the water-wheel to introduce the boring and finiſhing bars and cutters, it is then preſſed forwards upon this bar by means of levers, weights, &c. and the water-wheel being ſet a going, the bar and fullers are turned round, and clean out and ſmooth the caliber to its proper dimenſions.

Experience at laſt pointed out many inconveniences ariſing from the method of caſting guns *hollow*, and widening the calibers by theſe boring bars. For the body of iron of the hollow gun, being, at caſting, in contact with the core that made the caliber within-ſide, and with the mould without-ſide, began to conſolidate towards theſe ſides in the firſt place ſooner than in the intermediate ſpace, where of courſe the contraction of the iron takes place; by which means, all guns caſt hollow became more or leſs ſpongy where they ought to have been moſt compact; and numberleſs cavities alſo were created round the cores, from ſtagnated air generated in them, which were too deep to be cut out by the boring.

To remedy theſe defects, iron ordnance as well as braſs is now univerſally caſt ſolid, by which means the column of metal is greatly enlarged, and the grain more compreſſed; and the contraction becomes in the heart of the column, and conſequently is cut out by the perforation for the caliber.

Guns are bored out of the ſolid reverſely from the hollow method. The piece A (pl. XXI.) is placed upon two ſtandards BB, by means of two journeys, turned round by a water-wheel; the breech D being introduced into the central line of the wheel, with the muzzle towards the ſliding carriage E, which is preſſed forwards by a ratch F, and weights in the ſame way as the gun-carriage was in hollow-boring. Upon this ſliding carriage is fixed, truly horizontal and central to the gun, the drill-bar G, to the end of which is fixed a carp's tongue drill or cutter H; which, being preſſed forward upon the piece whilſt it is turning round, perforates the bore, which is afterwards finiſhed with bars and cutters as the hollow guns were.

The machinery for boring of ordnance is ſometimes put in motion by a ſteam-engine: and in this way, from 18 to 24 great guns have been boring at the ſame time; the borer in each piece being brought up to its proper place in the gun, by a lever and weights. In this method of bringing up the borer the preſſure may always be made equable, and the motion of the borer regular; but the diſadvantage is, that without due attention the borer may work up too far towards the breach, and the piece be ſpoiled. In the Royal Arſenal at Woolwich, only one piece is bored at a time in the ſame mill: the gun to be bored lies with its axis parallel to the horizon, and in that poſition is turned round its axis by means of wheel-work, moved by one or more horſes. The borer is laid, as above deſcribed, in the direction of the axis of the gun, and is incapable of motion in any direction except that of its length; and in this direction it is conſtantly moved by means of a ſmall rack-wheel, kept in proper motion by two men, who thus make the point of the borer ſo to bear againſt the part of the gun that is boring, as to pierce and cut it. The outſide of the gun is ſmoothed at the ſame time by men with inſtruments fit for the purpoſe, whilſt it turns round, ſo that the bore may be exactly in the centre of the metal.

In this way the boring is performed with great nicety, the guns ſcarcely ever failing in the examination. But in theſe mills the horſes work to great diſadvantage, the diametersof the walks in which they move being far too ſmall. See the introductory part of this volume, art. 76.

PARALLEL MOTION, is a term uſed among practical mechanics to denote the rectilinear motion of a piſton rod, &c. in the direction of its length: and contrivances by which ſuch alternate rectilinear motions are converted into rotatory ones, and *vice verſa*, in pumps, ſteam-engines, ſaw-mills, &c. are uſually called contrivances for parallel motions.

In motions of this kind it is generally thought a deſirable thing to give the piſton rod, the ſaw, or the like, a uniform velocity through the whole of its progreſs; then to bring it at once to reſt, again to give it inſtantaneouſly a finite velocity in the oppoſite direction, and ſo on. But this ſeems impoſſible in nature; all changes of motion *which we obſerve* are gradual, becauſe all impelling bodies have ſome elaſticity or ſoftneſs by which they yield to compreſſion: and, in the way in which piſtons are commonly moved, *viz.* by cranks, or ſomething analogous to them, the motion is *very ſenſibly* gradual. Hence, it may be obſerved that moſt attempts to correct theſe inequalities in motion are miſplaced; and if they could be accompliſhed would greatly injure the pump or other machine. One of the beſt methods of producing this effect is to make the piſton-rod conſiſt of two parallel bars, having teeth in the ſides which front each other. Let a toothed wheel be placed between them, having only the half of its circumference furniſhed with teeth. It is evident, without any further deſcription, that if this wheel be turned uniformly round its axis, the piſton-rod will be moved uniformly up and down without intermiſſion. This has often been put in practice, and the piſton-rod made to work between grooved rollers; but the machine always went by jolts, and ſeldom laſted a few days. Unſkilled mechaniſts attributed this to defect in the execution: but the fault is eſſential, and lies in the principle. The machine could not perform one ſtroke if the firſt mover did not ſlacken a little, or the different parts of the machine did not yield by bending, or by compreſſion; and no ſtrength of materials could withſtand the violence of the ſtrains at every reciprocation of the motion. This is chiefly experienced in great works which are put in motion by a water-wheel, or ſome other equal power exerted on the maſs of matter of which the machine conſiſts. The water-wheel being of great weight moves with conſiderable ſteadineſs or uniformity; and when an additional reſiſtance is oppoſed to it by the beginning of a new ſtroke of the piſton, its great quantity of motion is but little affected by this addition, and it proceeds very little retarded; and the machine muſt either yield a little by bending and compreſſion, or go to pieces, which is the common event. Cranks are free from this inconvenience, becauſe they accelerate the piſton gradually, and bring it gradually to reſt, while the water-wheel moves round with almoſt perfect uniformity. The only inconvenience (and it may be conſiderable) attending this ſlow motion of a piſton at the beginning of its ſtroke is, that the valves do not ſhut with rapidity, ſo that ſome water gets back through them. But when they are properly formed and loaded, this is but trifling.

It would ſeem, then, that thoſe contrivances in which the piſton-rod communicates the rotatory motion by means of a crank, or ſomething ſimilar in its effect, are moſt fit to be adopted in practice; and that the attempts of mechaniſts in this point of view may in all probability be properly reſtrained to the methods of keeping the piſton-rod, &c. from deviating to any ſide, during its alternate motion. Two or three of the beſt methods of performing this, with which we are acquainted, are the following.

1. Let a fixed circular ring whoſe diameter is equal to the ſtroke of the piſton have teeth all round the interior part of its circumference; and let a ſmaller wheel whoſe diameter is only half that of the ring have equal teeth on the exterior part of its rim, to play into the teeth of the ring: let the axis of the wheel to which the rotatory motion is to be communicated paſs through the centre of the larger ring; and let a moveable bar join the centre of this ring to that of the ſmaller wheel. Then, if the upper extremity of the piſton-rod be attached to a pin fixed on the rim of the inner wheel, at the place where the two wheels are in contact in their loweſt point, and the rod be put into motion, it will cauſe the ſmall wheel to revolve upon the inner part of the fixed ring, and by this means give the propoſed rotatory motion to the axis paſſing through the centre of the ring. At the ſame time the extremity of the piſton-rod will be confined to move in the vertical diameter of the ring: becauſe it is made to deſcribe an epicycloid of that kind which is formed by a circle rolling along the inſide of another circle of double diameter; in which caſe, it is well known, the epicycloid becomes a diameter of the larger circle, and the ſmaller circle makes two complete revolutions while it is moving from any one point of the larger circle to the ſame point again.

This contrivance was deviſed, we believe, by Mr. White, an Anglo-American. It is almoſt unneceſſary to obſerve that the converſe is equally applicable in the converſion of a rotatory into a parallel motion.

2. Another method is repreſented in figure 10. pl. XXIII.

where the piſton-rod is kept from deviation. A is the cylinder, B the piſton, C the piſton-rod, D the crank, and E the connecting rod of the crank and piſton-rod. When the piſton is at *e*, the crank is at *a*; when the piſton is at B, the crank is either at *g* or *b*; and when the piſton is at *g*, the crank is at *f*: ſo that when the motion of the crank is uniform that of the piſton is variable. The rod H equal in length to the crank D moves about the centre F, and is joined to one end of the rod I, to the other end of which is connected the ſocket L that receives the top end of the piſton-rod. A certain point *m* is taken at pleaſure in the rod I, to carry a ſhort axle for the rods K, which are broken in the figure to ſhew the ſocket L. To find the centre of motion of the rods K, move the end L of the rod I up and down in the vertical line C *f a*, and mark three poſitions *n*, *m*, *r*, of the point *m* on that rod; deſcribe a circle to paſs through thoſe three points; its radius will be equal to the length of the rods K, and its centre will be the point where thoſe rods muſt be fixed to a bolt or axle in the framing. This contrivance cauſes the top of the piſton-rod to move from P by L to O, and back again by L to *p*; and the dotted lines ſhew the poſition of the ſeveral rods at the extremities of the motion.

In fig. 11. pl. XXIII. we have given a horizontal ſection, to ſhew the connection of H, I, K, &c. pointing out in what way I graſps L, and E both. The inequality of the piſton's motion will be reduced by making the connecting rod E as long as circumſtances will permit.

If the rod I were extended to the left of the point *p*, the ſame kind of apparatus would become a lever with a moveable fulcrum, by means of which a weight might be raiſed in a vertical line from P to O; or a pump piſton-rod worked without deviation.

3. A third method is exhibited in fig. 8. pl. XXIII. where there are three rods A, B, and C, beſides the connecting rod D. The rods A and C are of equal lengths, and the connecting rod is attached to the middle point of the rod B. The guides A, and C, are fixed at their ends E, and F, by bolts to the framing. Thus the point B, to which is fixed the top of the piſton-rod, is made to move in the right line *b* B *b'*; and the dotted lines ſhew the poſitions of the rods at the extremities of the ſtroke. Fig. 7. ſhews in what way the piſton-rod P and connecting rod D might be joined to the guides B and C.

This method and the preceding were deviſed by Mr. William Dryden: a mechanic whoſe ingenuity needs not our encomium.

4. Another method is ſhewn in fig. 12. pl. XXIII. A and B are two bolts in the framing at equal diſtances on oppoſite ſides

of the vertical line in which the piſton is to move. AC, BD, two bars of equal length, each equal to about half the diſtance AB. CL, DL, two other equal bars, rather more than double the length of the former, moving freely on joints at C and D. At L is a ſocket, as in fig. 10. to receive the top of the piſton-rod, and to which the bars CL, DL, and the connecting rod E, are attached. By this contrivance it is obvious, that as the rods BC, BD, turn upon the centres A, B, in contrary directions, the piſton-rod will be made to move in the right line PM without deviation; NM being the length of the ſtroke. The relative lengths of the bars AC, CL, may be varied at pleaſure: but thoſe we have mentioned will be found as well as any in practice.

5. A piſton-rod may alſo be kept from deviating to either ſide, while it gives motion to a crank, and *vice verſa*, thus; place a croſs-bar at a diſtance from the end of the cylinder rather greater than the ſtroke of the piſton, and make the piſton-rod play in a hole made in this croſs-bar; let an axle be fixed to a proper point of the piſton-rod between the end of the cylinder and the croſs-bar, and from this axle let two equal connecting rods paſs to the crank, one on each ſide the croſs-bar: by this ſimple contrivance the alternating and circular motions may be communicated to the different parts of the machine with great facility.

PARCIEUX'S AREOMETER. See Vol. I. art. 401, 409.

PATERNOSTER-WORK. See HYDRAULIC *Engines*, No. 5.

PENDULUM, in mechanics, any heavy body, ſo ſuſpended as that it may ſwing backwards and forwards, about ſome fixed point, by the force of gravity.

Theſe alternate aſcents and deſcents of the pendulum are called its oſcillations, or vibrations; each complete oſcillation being the deſcent from the higheſt point on one ſide down to the loweſt point of the arch, and ſo on up to the higheſt point on the other ſide. The point round which the pendulum moves, or vibrates, is called its centre of motion, or point of ſuſpenſion; and a right line drawn through the centre of motion, parallel to the horizon, and perpendicular to the plane in which the pendulum moves, is called the axis of oſcillation. There is alſo a certain point within every pendulum, into which, if all the matter that compoſes the pendulum were collected, or condenſed as into a point, the times in which the vibrations would be performed would not be altered by ſuch condenſation; and this point is called centre of oſcillation. The length of the pendulum is always eſtimated by the diſtance of this point below the centre of motion; being uſually near the bottom of the pendulum; but in a cylinder, or any other uniform priſm or rod, it is at the diſtance of one-third from the bottom, or two-thirds below the centre of motion.

The length of a pendulum, ſo meaſured to its centre of oſcillation that it will perform each vibration in a ſecond of time, thence called the ſecond's pendulum, has, in the latitude of London, been generally taken at $39\frac{2}{10}$ or $39\frac{1}{5}$ inches; but by ſome very ingenious and accurate experiments, the late celebrated Mr. George Graham found the true length to be $39\frac{128}{1000}$, inches, or $39\frac{1}{8}$ inches very nearly.

The length of the pendulum vibrating ſeconds at Paris was found by Varin, Des Hays, De Glos, and Godin, to be $440\frac{5}{6}$ lines; by Picard $440\frac{1}{2}$ lines; and by Mairan $440\frac{17}{30}$ lines.

In our firſt volume (book II. ch. ii.), where the theory of pendulums was laid down, we remarked that the length of the ſecond pendulum was different in different parts of the earth. It would not be eaſy to exhibit a completely accurate theorem for the length of the pendulum at all places on the earth's ſurface: but the beſt and moſt ſimple with which we are acquainted was firſt given by Mr. *Krafft* in the New Peterſburgh Memoirs, vol. vii. It is this: if x be the length of a pendulum that ſwings ſeconds in any given latitude l, and in a temperature of 10 degrees of Reaumur's thermometer, then will the length of that pendulum, for that latitude, be thus expreſſed, viz.

$$x = (439{\cdot}178 + 2{\cdot}321 \times \text{ſin.}^2 l) \text{ lines of a French foot.}$$

And this expreſſion agrees very nearly, not only with all the experiments made on the pendulum in Ruſſia, but alſo with thoſe of Mr. Graham, and thoſe of Mr. Lyons in 79° 50′ north latitude, where he found its length to be 241·38 lines.

Since metals expand by heat and contract by cold, pendulums, which are conſtituted chiefly of metal, muſt be ſubject to variations in conſequence of ſuch expanſion and contraction; and various are the contrivances which have been deviſed to correct the errors in the eſtimates of time which have been thus produced: a few of theſe will here be deſcribed.

The vulgar method of remedying the inconvenience ariſing from the extenſion and contraction of the rods of common pendulums is by applying the bob, or ſmall ball, with a ſcrew, at the lower end; by which means the pendulum is at any time made longer or ſhorter, as the ball is ſcrewed downwards or upwards; and thus the time of its vibration is kept continually the ſame.

The *gridiron* PENDULUM was the invention of Mr. John Harriſon, a very ingenious artiſt, and celebrated for his invention of the watch for finding the difference of longitude at ſea, about the year 1725; and of ſeveral other time-keepers and watches ſince that time: for all which he received the parliamentary reward of between 20 and 30 thouſand pounds. It conſiſts of 5 rods of ſteel, and 4 of braſs, placed in an alternate order; the middle rod being of ſteel, by which the pendulum ball is ſuſpended: theſe rods of braſs and ſteel, thus placed in an alternate order, and ſo connected with each other at their ends, that while the expanſion of the ſteel rods has a tendency to lengthen the pendulum, the expanſion of the braſs rods, acting upwards, tends to ſhorten it. And thus, when the lengths of the braſs and ſteel rods are duly proportioned, their expanſions and contractions will exactly balance and correct each other, and ſo preſerve the pendulum invariably of the ſame length. The ſimplicity of this ingenious contrivance is much in its favour; and the difficulty of adjuſtment ſeems the only objection to it.

Mr. Harriſon, in his firſt machine for meaſuring time at ſea, applied this combination of wires of braſs and ſteel, to prevent any alterations by heat or cold; and in the machines or clocks he has made for this purpoſe, a like method of guarding againſt the irregularities ariſing from this cauſe is uſed.

The principal objections to this mode of compenſation are, 1ſt. The difficulty of exactly adjuſting the lengths of the rods. 2dly. Of proportioning their thickneſs, ſo that they ſhall all begin to expand or contract at the ſame inſtant. 3dly. The connecting bars of a pendulum thus conſtructed are apt to move by ſtarts. 4thly. This kind of pendulum is more expoſed to the air's reſiſtance than a ſimple pendulum.

Another excellent contrivance for the ſame purpoſe is deſcribed by M. Thiout, a French author on clock-making. It was uſed in the north of England by an ingenious artiſt about 40 years ago. This invention is as follows: a bar of the ſame metal with the rod of the pendulum, and of the ſame dimenſions, is placed againſt the back part of the clock-caſe: from the top of this a part projects, to which the upper part of the pendulum is connected by two fine pliable chains or ſilken ſtrings, which juſt below paſs between two plates of braſs, whoſe lower edges will always terminate the length of the pendulum at the upper end. Theſe plates are ſupported on a pedeſtal fixed to the back of the caſe. The bar reſts upon an immoveable baſe at the lower part of the caſe, and is inſerted into a groove; by which means it is always retained in the ſame poſition. From this conſtruction, it is evident that the extenſion or contraction of this bar, and of the rod of the pendulum, will be equal, and in contrary directions. For, ſuppoſe the rod of the pendulum to be expanded any given quantity by heat; then, as the lower end of the bar reſts upon a fixed point, the bar will be expanded upwards, and raiſe the upper end of the pendulum juſt as much as its length was increaſed; and hence its length below the plates will be the ſame as before.

In Voigt's Magazin fuer den neveſten Zuſtande de Naturkunde, vol. iv. are deſcribed the gridiron pendulums of Mr. Benzenberg, which are compoſed of *lead* and *iron*. Mr. B. was induced to employ lead on account of its great dilatability, which is to iron as 2·57 to 1, ſo that 16·5 inches of lead compenſate 1·3 of iron; and he choſe iron in preference to ſteel, becauſe eaſier to work. The compenſation was made by a ſingle rod in the centre, 16½ inches long, French meaſure, and half an inch thick. It was ſimply pinned into gorges in the croſs-piece of copper; but the other parts of the gridiron were rivetted in the uſual way. The iron rods were made of the beſt thick iron wire.

The materials of this pendulum are cheap, and it may be made in a couple of days. As the preſſure takes place in a vertical direction, there is no danger, according to Mr. B., of rods of theſe dimenſions bending.

To correct the compenſation, the central rod of lead muſt be left ſo long that we may be ſure the compenſation is in exceſs. The quantity of error may then be found by the freezing apparatus, and how much it is requiſite to cut from the rod may be calculated with the greateſt exactneſs.

The *mercurial* PENDULUM was the invention of the ingenious Mr. Graham, in conſequence of ſeveral experiments relating to the materials of which pendulums might be formed, in 1715. Its rod is made of braſs, and branched towards its lower end, ſo as to embrace a cylindric glaſs veſſel 13 or 14 inches long, and about 2 inches diameter; which being filled about 12 inches deep with mercury, forms the weight or ball of the pendulum. If upon trial the expanſion of the rod be found too great for that of the mercury, more mercury muſt be poured into the veſſel: if the expanſion of the mercury exceeds that of the rod, ſo as to occaſion the clock to go faſt with heat, ſome mercury muſt be taken out of the veſſel, ſo as to ſhorten the column. And thus may the expanſion and contraction of the quickſilver in the glaſs be made exactly to balance the expanſion and contraction of the pendulum rod, ſo as to preſerve the diſtance of the centre of oſcillation from the point of ſuſpenſion invariably the ſame.

Mr. Graham made a clock of this ſort, and compared it with one of the beſt of the common ſort, for three years together; when he found the errors of his but about one-eighth part of thoſe of the latter. Philoſ. Tranſ. numb. 392.

The only defect we have ever heard aſcribed to this pendulum, is that the expanſion of the mercury commences ſooner than that of the rod: but, after all, there are many ſtrong proofs of its practical excellence.

The *lever* PENDULUM. From all that appears concerning this conſtruction of a pendulum, we are inclined to believe that the idea of making the difference of the expanſion of different metals operate by means of a lever originated with Mr. Graham, who in the year 1737 conſtructed a pendulum, having its rod compoſed of one bar of ſteel between two of braſs, which acted upon the ſhort end of a lever, to the other end of which the ball or weight of the pendulum was ſuſpended.

This pendulum however was, upon trial, found to move by jerks; and therefore laid aſide by the inventor, to make way for the mercurial pendulum, juſt mentioned.

Mr. Short informs us in the Philoſ. Tranſ. vol. 47, art. 88, that a Mr. Frotheringham, a quaker in Lincolnſhire, cauſed a pendulum of this kind to be made: it conſiſted of two bars, one of braſs, and the other of ſteel, faſtened together by ſcrews, with levers to raiſe or let down the bulb; above which theſe levers were placed. M. Caſſini too, in the Hiſtory of the Royal Academy of Sciences at Paris, for 1741, deſcribes two ſorts of pendulums for clocks, compounded of bars of braſs and ſteel; and in which he applies a lever to raiſe or let down the bulb of the pendulum, by the expanſion or contraction of the bar of braſs.

Mr. John Ellicott alſo, in the year 1738, conſtructed a pendulum on the ſame principle, but differing from Mr. Graham's in many particulars. The rod of Mr. Ellicott's pendulum was compoſed of two bars only; the one of braſs and the other of ſteel. It had two levers, each ſuſtaining its half of the ball or weight; with a ſpring under the lower part of the ball to relieve the levers from a conſiderable part of its weight, and ſo to render their motion more ſmooth and eaſy. The one lever in Mr. Graham's conſtruction was above the ball: whereas both the levers in Mr. Ellicott's were within the ball; and each lever had an adjuſting ſcrew, to lengthen or ſhorten the lever, ſo as to render the adjuſtment the more perfect. See the Philoſ. Tranſ. vol. 47, p. 479; where Mr. Ellicott's methods of conſtruction are deſcribed, and illuſtrated by figures.

Notwithſtanding the great ingenuity diſplayed by theſe eminent artiſts on this conſtruction, it muſt further be obſerved, in the hiſtory of improvements of this nature, that Mr. Cumming, another eminent artiſt, has given, in his Eſſays on the Principles of Clock and Watch-work, Lond. 1766, an ample deſcription, with plates, of a conſtruction of a pendulum with levers, in which it ſeems he has united the properties of Mr. Graham's and Mr. Ellicott's, without being liable to any of the defects of either. The rod of this pendulum is compoſed of one flat bar of braſs, and two of ſteel: he uſes three levers within the ball of the pendulum; and, among many other ingenious contrivances, for the more accurate adjuſting of this pendulum to mean time, it is provided with a ſmall ball and ſcrew below the principal ball or weight, one entire revolution of which on its ſcrew will only alter the rate of the clock's going one ſecond per day; and its circumference is divided into 30, one of which diviſions will therefore alter its rate of going one ſecond in a month.

Mr. Edward Troughton has lately invented a *tubular* pendulum, which acts on the principle of the gridiron pendulum: in this conſtruction the apparent rod is a tube of braſs reaching from the bob nearly to the top; this contains another tube and five wires in its belly, ſo diſpoſed as to produce altogether (like the nine-bar gridiron of Harriſon) three expanſions of ſteel downwards, and two of braſs upwards; whoſe lengths being inverſely proportioned to their dilatation, when properly combined, deſtroy the whole effect that either metal would have ſingly. The ſmall viſible part of the rod near the top is a braſs tube, whoſe uſe is to cover the upper end of the middle wire, which is ſingle, and otherwiſe unſupported. Drawings of this pendulum may be ſeen in Nicholſon's Journal, No. 36. N. S.

After all, ſo long as the vibration of pendulums is performed in a medium of varying denſity we muſt not look for an accurate time-piece for aſcertaining the longitude, &c.; unleſs a ſelf-correcting mercurial pendulum could be contrived, adapted to counteract the ſmalleſt variations effected by the ambient air. The errors of a time-piece are but half corrected by the fabrication of pendulums adapted to obviate the expanſion of metals by increaſe of temperature, if the works themſelves ſtill remain conſtructed of ſuch expanſible materials. A correct time-piece, therefore, will be that of which not only the works and pendulum are conſtructed of the leaſt expanſible materials, but the pendulum itſelf ſhall vibrate in a medium of unalterable denſity; a deſideratum only to be obtained by cauſing the vibrations to be performed *in vacuo*, or by a ſelf-correcting pendulum, as above alluded to. Mr. G. J. Wright, of Kennington, who has ſome obſervations on this ſubject in Tilloch's Philoſophical Magazine, No. 57. ſays the beſt ſubſtance to compoſe the works of a correct time-keeper is ivory, or the horn of the narwhal or ſea-unicorn (which is almoſt entirely compoſed of enamel); eſpecially if any means were known of increaſing their hardneſs ſo as to vie with the metals.

The moſt general remedy againſt the chief inconveniences of pendulums, is to make them *long*, to vibrate in *ſmall* arcs; and to have the bobs as ponderous as is conſiſtent with the ſtructure of the machine. In thoſe caſes where it is wiſhed to increaſe the time of vibration without increaſing the length of the pendulum, recourſe muſt be had to the *angular* pendulum, the theory of which has been given in art. 311, vol. I.

PENSTOCK is a ſluice or floodgate, ſerving to retain or let go at pleaſure the water of a mill-pond. The following is a deſcription of a pentrough and ſtock for equaliſing the water falling on water-wheels, by George Quayle, eſq.

To inſure a regular ſupply of water on the wheel, and to obviate the inconveniences ariſing from the uſual mode of delivering it from the bottom of the pentrough, this method is deviſed of regulating the quantity delivered by a float, and taking the whole of the water from the ſurface.

Section of the pentrough. (Plate XVI. fig. 4.) A, the entrance of the water. B, the float, having a circular aperture in the centre; in which is ſuſpended C, a cylinder, running down in the caſe E below the bottom of the pentrough. This is made water tight at the bottom of the pentrough at F, by a leather collar placed between two plates, and ſcrewed down to the bottom.

The cylinder is ſecured to the float ſo as to follow its riſe and fall; and the water is admitted into it through the opening in its ſides, and there, paſſing through the box or caſe E, riſes and iſſues at G on the wheel. By this means, a uniform quantity of water is obtained at G; which quantity can be increaſed or diminiſhed by the aſſiſtance of a ſmall rack and pinion attached to the cylinder, which will raiſe or depreſs the cylinder above or under the water line of the float; and, by raiſing it up to the top, it ſtops the water entirely, and anſwers the purpoſe of the common ſhuttle. This pinion is turned by the handle H, ſimilar to a winch-handle; and is ſecured from running down by a ratchet-wheel at the oppoſite end of the pinion axis.

K and L are two upright rods to preſerve the perpendicular riſe and ſinking of the float, running through the float, and ſecured at the top by brackets from the ſides.

M, a board let down acroſs the pentrough nearly to the bottom, to prevent the horizontal impulſe of the water from diſturbing the float.'

Fig. 5. A tranſverſe ſection, ſhewing the mode of fixing the rack and pinion, and their ſupports, on the float. The rack is

inſerted into a piece of metal running acroſs the cylinder near the top. That the water may paſs more freely when nearly exhauſted, the bottom of the cylinder is not a plane, but is cut away ſo as to leave two feet, as at C, fig. 4. The float is alſo kept from lying on the pentrough bottom by four ſmall feet; ſo that the water gets under it regularly from the firſt.

Fig. 6. An enlarged view of the cylinder, ſhewing the rack and ratchet-wheel, with the click, and one of the openings on the ſide of the cylinder: the winch or handle being on the oppoſite ſide, and the pinion, by which the rack is raiſed, incloſed in a box between them. Tranſactions of the Society of Arts, vol. XI. A. D. 1793.

PERSIAN-WHEEL. See Hydraulic *Engines*. No. 4.

PILE-ENGINE, a machine by which piles are driven into the earth for the foundations of piers and other ſtructures.

In pile-engines the contrivance conſiſts in drawing up a great weight, called a ram or hammer, to a moderate height, and then letting it fall freely with a conſiderable momentum upon the head of the pile. In the moſt ſimple pile engines the ram is drawn up by men pulling at a cord running over a fixed pulley, and ſuffering the cord to ſlip from their hands when the weight is ſufficiently elevated. Among more complex engines, the beſt we have ſeen are thoſe invented by Mr. Vauloue and by Mr. S. Bunce.

Deſcription of Vauloue's pile-engine. (See pl. XXII.) A is a great upright ſhaft or axle, on which are the great wheel B and the drum C, turned by horſes joined to the bars S, S. The wheel B turns the trundle X, on the top of whoſe axis is the fly O, which ſerves to regulate the motion, as well as to act againſt the horſes, and to keep them from falling when the heavy ram Q is diſcharged to drive the pile P down into the mud in the bottom of the river. The drum C is looſe upon the ſhaft A, but is locked to the wheel B by the bolt Y. On this drum the great rope HH is wound; one end of the rope being fixed to the drum, and the other to the follower G, to which it is conveyed the pulleys I and K. In the follower G is contained the tongs F, that take hold of the ram Q by the ſtaple R for drawing it up. D is a ſpiral or fuſee fixed to the drum, on which is wound the ſmall rope T that goes over the pulley U, under the pulley V, and is faſtened to the top of the frame at 7. To the pulley-block V is hung the counterpoiſe W, which hinders the follower G from accelerating as it goes down to take hold of the ram; for, as the follower tends to acquire velocity in its deſcent, the line T winds downwards upon the fuſee on a larger and larger radius, by which means the counterpoiſe W acts ſtronger and ſtronger againſt it; and ſo allows it to come down with only a moderate and uniform velocity. The bolt Y locks the drum to the great wheel, being puſhed upward by the ſmall lever 2, which goes through a mortiſe in the ſhaft A, turns upon a pin in the bar 3, fixed to the great wheel B, and has a weight 4, which always tends to puſh up the bolt Y through the wheel into the drum. L is the great lever turning on the axis *m*, and reſting upon the forcing bar 5, 5, which goes through a hollow in the ſhaft A, and bears up the little lever 2.

By the horſes going round, the great rope H is wound about the drum C, and the ram Q is drawn up by the tongs F in the follower G, until the tongs come between the inclined planes E; which, by ſhutting the tongs at the top, opens it at the foot, and diſcharges the ram, which falls down between the guides *b b* upon the pile P, and drives it by a few ſtrokes as far into the mud as it will go; after which, the top part is ſawed off cloſe to the mud by an engine for that purpoſe. Immediately after the ram is diſcharged, the piece 6 upon the follower G takes hold of the ropes *a a*, which raiſe the end of the lever L, and cauſe its end N to deſcend and preſs down the forcing bar 5 upon the little lever 2, which, by pulling down the bolt Y, unlocks the drum C from the great wheel B; and then the follower being at liberty comes down by its own weight to the ram; and the lower ends of the tongs ſlip over the ſtaple R, and the weight of their heads cauſes them to fall outward and ſhut upon it. Then the weight 4 puſhes up the bolt Y into the drum, which locks it to the great wheel, and ſo the ram is drawn up as before.

As the follower comes down, it cauſes the drum to turn backward, and unwinds the rope from it, whilſt the horſes, great wheel, trundle, and fly, go on with an uninterrupted motion; and as the drum is turning backward, the counterpoiſe W is drawn up, and its rope T wound upon the ſpiral fuſee D.

There are ſeveral holes in the under ſide of the drum, and the bolt Y always takes the firſt of them that it finds, when the drum ſtops by the falling of the follower upon the ram; until which ſtoppage the bolt has not time to ſlip into any of the holes.

The peculiar advantages of this engine are, that the weight called the ram, or hammer, may be raiſed with the leaſt force; that, when it is raiſed to a proper height, it readily diſengages itſelf and falls with the utmoſt freedom; that the forceps or tongs are lowered down ſpeedily, and inſtantly of themſelves again lay hold of the ram and lift it up.

This engine was placed upon a barge on the water, and ſo was eaſily conveyed to any place deſired. The ram was a ton weight; and the guides *b b*, by which it was let fall, were 30 feet high.

Deſcription of Bunce's Pile-engine.

Fig. 1 and 2. plate XXII. repreſent a ſide and front ſection of the machine. The chief parts are, A, fig. 1. which are two endleſs ropes or chains, connected by croſs pieces of iron, B (fig. 2.), correſponding with two croſs grooves cut diametrically oppoſite in the wheel C (fig. 1.), into which they are received; and by which means the rope or chain A is carried round. FHK is a ſide-view of a ſtrong wooden frame moveable on the axis H. D is a wheel, over which the chain paſſes and turns within at the top of the frame. It moves occaſionally from F to G upon the centre H, and is kept in the poſition F by the weight I fixed to the end K. In fig. 3. L is the iron ram, which is connected with the croſs pieces by the hook M. N is a cylindrical piece of wood ſuſpended at the hook at O, which, by ſliding freely up the bar that connects the hook to the ram, always bring the hook upright upon the chain when at the bottom of the machine, in the poſition of GP. See fig. 1.

When the man at S turns the uſual crane-work, the ram being connected to the chain and paſſing between the guides, is drawn up in a perpendicular direction; and when it is near the top of the machine, the projecting bar Q of the hook ſtrikes againſt a croſs piece of wood at R (fig. 1.), and conſequently diſcharges the ram; while the weight I of the moveable frame inſtantly draws the upper wheel into the poſition ſhewn at F, and keeps the chain free of the ram in its deſcent. The hook, while deſcending, is prevented from catching the chain by the wooden piece N: for that piece being ſpecifically lighter than the iron weight below, and moving with a leſs degree of velocity, cannot come into contact with the iron till it is at the bottom and the ram ſtops. It then falls, and again connects the hook with the chain, which draws up the ram as before.

In this machine, as well as Vauloue's, the motion of the firſt wheel is uninterrupted, ſo that very little time is loſt in the operation: with a ſlight alteration it might be made to work with horſes. It has the advantage over Vauloue's engine in point of ſimplicity; it may be originally conſtructed at leſs expence, and is not ſo liable to be deranged. Both, however, are ingenious performances, and part of their conſtruction might be advantageouſly introduced into other machines.

PIPES, for conveying of water, for pumps, water-engines, &c. are uſually of lead, iron, earth, or wood: the latter are uſually made of oak or elder. Thoſe of iron are caſt in forges;

their uſual length is about two feet and a half: ſeveral of theſe are commonly faſtened together by means of four ſcrews at each end, with leather or old hat between them, to ſtop the water. Thoſe of earth are made by the potters; theſe are fitted into one another, one end being always made wider than the other. To join them the cloſer and prevent their breaking, they are covered with tow and pitch: their length is uſually about that of the iron pipes. The wooden pipes are trees bored with large iron augers of different ſizes, beginning with a leſs, and then proceeding with a larger ſucceſſively; the firſt being pointed, the reſt being formed like ſpoons, increaſing in diameter from one to ſix inches or more: the pipes are fitted into the extremities of each other (as repreſented in pl. XXII. fig. 1.), and are ſold by the foot.

Wooden pipes are bored either by a borer advancing horizontally while the wood to be pierced is turned round, in ſome ſuch manner as in boring of ordnance; or, by cauſing the timber to be gradually advanced, while the borer turns round: the latter method is the moſt common. The apparatus moſt frequently adopted, when the firſt mover is a ſtream of water, is that invented by M. Morel, and deſcribed by Belidor (Architecture Hydraulique, tom. I.). This machinery is repreſented at pl. XXII. fig. 1. where the vertical wheel A is put into motion by water deſcending upon it through a trough or ſloping canal: upon the horizontal axle of this wheel is a cog-wheel B, which gives motion to the lanterns C, D, the common axis of theſe lanterns being in a vertical poſition. The lantern D turns at the ſame time two cog-wheels E and F: the firſt, E, which is vertical, turns the auger that bores the wood; and the ſecond, F, which is horizontal, has attached to it by a pin which is at a ſmall diſtance from its centre, a lever or arm H, with a hook at its end, taking into the indentations of one of the wheels of the carriage that carries the wood to be bored. Another lever, I, hanging upon the former, is prevented from falling by a ſpring, and puſhes by its extremity againſt the notches in the lower end of the ſame wheel. Thus, as the cog-wheel turns round, the carriage-wheel is firſt pulled forward by the hook and lever H, and then puſhed backward as far by the arm I; by this means cauſing a pinion upon the axle of the carriage-wheel to advance the rackwork above it, together with the timber to be bored: ſo that the timber is advanced by a ſlight reciprocating motion of the carriage. The auger, being generally ſome feet in length, plays in holes in two pieces L, L, which retain it in its horizontal poſition; and thus it forms a cylindrical cavity in the wood, as required.

PLANET WHEELS are wheels by whoſe mutual connection a variable angular motion, ſuch as that of the radius vector of a planet in its orbit, may be exhibited. The common contrivance now in uſe for this purpoſe was invented, we think, by Deſaguliers: it conſiſts of two elliptical wheels connected either by teeth running into each other, or by a band; theſe wheels revolve on their foci, and while the driving ellipſes move uniformly, the radius vector of the other has the required motion.

A much older, and at the ſame time *far better*, method than that of Deſagulier's, is deſcribed in the firſt volume of the Recueil des Machines et Inventions approuvées par l'Acad. Roy. des Sci. 1699: it was the invention of M. *Joli de Dijon*. The following account of this method is tranſlated from the work juſt mentioned.

If it be deſired to move a wheel of 24 teeth by a pinion of 6, in ſuch a manner that in ſome parts of its revolution it ſhall move as ſwiftly as if it had but 12 teeth, and in other parts as ſlowly as if it had 48 teeth, the method of accompliſhing this is as follows:

1. Deſcribe the rectangle LMNO (fig. 1. pl. XXIII.) having its ſide NO equal to the radii of the great wheel and the pinion taken together, and its breadth LN equal to their thickneſs; which laſt muſt be greater the more conſiderable the inequality of the propoſed movement. Let NO be ſo divided in Q, that QO may be to QN as 6 to 48, that is to ſay, reciprocally as the velocity of the pinion to the greateſt velocity of the wheel. Alſo divide LM in P in the proportion of 6 to 12, or reciprocally as the velocity of the pinion to the leaſt velocity of the wheel. Then join PQ, and draw as many lines SR parallel to LM, as there are intended to be teeth in the great wheels; upon which write the degrees of velocity they expreſs, which are in the inverſe ratio of their lengths.

2. Let two truncated cones be formed in the lathe; one equal to that which would be formed by the revolution of the trapezoid LPQN about LN as an axis; and the other equal to what would be formed by the revolution of the trapezoid PQMO about the axis MO. On the largeſt of theſe two cones let the circles generated by the revolution of the points P, T, Q, be marked and diſtinguiſhed by the ſame numeral figures as the correſponding parallels of the rectangle LO. Upon the two baſes of the conic fruſtrum deſcribe radial lines, which ſhall make angles at the centre (fig. 3.) in the ſame proportion to each other as the intended velocities of the wheel, as expreſſed in fig. 2. and let teeth be cut in the curve ſurface of the cone

correſponding with theſe lines: after this, look on the circles that expreſs the different velocities, and have been traced on the ſame ſurface, to find what part of each tooth ought to remain oppoſite its correſponding radius, and cut or file the reſt away. Thus will the teeth lie in an oblique or elliptical curve on the conical ſurface, as is exhibited in the figure by a darker ſhade. The pinion muſt be made of a regular conic ſhape, as is ſhewn at MO in fig. 3.

By this contrivance the largeſt or wideſt teeth will always meet the largeſt part of the pinion, and the narroweſt will correſpond with the ſmalleſt part: on which account, though the motion of the pinion be uniform, the wheel will be carried unequably, according to the aſſigned law.

In a ſimilar manner may planet-wheels be deſcribed to exhibit any other propoſed variation.

PRESS, a machine of wood, or iron, ſerving to ſqueeze any body very cloſe.

Preſſes uſually conſiſt of ſix pieces: two flat ſmooth planks, between which the things to be preſſed are laid; two ſcrews or worms faſtened to the lower plank, and paſſing through two holes in the upper; and two nuts in form of an S, that ſerve to drive the upper plank, which is moveable, againſt the lower, which is fixed.

PRESSES *uſed for expreſſing Liquors* are in moſt reſpects the ſame with the common preſſes, only the under plank is perforated with a great number of holes for the juice to run through. Others have only one ſcrew, or arbor, paſſing through the middle of the moveable plank, which deſcends into a kind of ſquare box full of holes, through which the juices flow as the arbor is turned.

PRESS *uſed by Joiners* to keep cloſe the pannels, &c. of wainſcot, conſiſts of two ſcrews, and two pieces of wood, four or five inches ſquare, and two or three feet long, whereof the holes at two ends ſerve for nuts to the ſcrews.

Founders' PRESS, is a ſtrong ſquare frame, conſiſting of four pieces of wood firmly joined together with tenons, &c. It is of various ſizes: two of them are required to each mould at the two extremes whereof they are placed; ſo as that, by driving wooden wedges between the mould and ſides of the preſs, the two parts of the mould for the metal may be preſſed cloſe together.

PRESS, *binders' cutting-*, is a machine uſed equally by bookbinders, ſtationers, and paſteboard-makers; conſiſting of two large pieces of wood in form of cheeks, connected by two ſtrong wooden ſcrews; which, being turned by an iron bar, draw together, or ſet aſunder, the cheeks, as much as is neceſſary for the putting in the books or paper to be cut. The cheeks are placed lengthwiſe on a wooden ſtand, in form of a cheſt, into which the cuttings fall. Aſide of the cheeks are two pieces of wood of the ſame length with the ſcrews, ſerving to direct the cheeks, and prevent their opening unequally. Upon the cheeks the plough moves, to which the cutting-knife is faſtened by a ſcrew; which has its key, to diſmount it, on occaſion, to be ſharpened.

The plough conſiſts of ſeveral parts; among the reſt, a wooden ſcrew or worm, which, catching within the nuts of the two feet that ſuſtain it on the cheeks, brings the knife to the book or paper which is faſtened in the preſs between two boards. This ſcrew, which is pretty long, has two directories, which reſemble thoſe of the ſcrews of the preſs. To make the plough ſlide ſquare and even on the cheeks ſo that the knife may make an equal paring, that foot of the plough where the knife is not fixed, ſlides in a kind of groove, faſtened along one of the cheeks. Laſtly, the knife is a piece of ſteel, ſix or ſeven inches long, flat, thin, and ſharp, terminating at one end in a point, like that of a ſword, and, at the other, in a ſquare form, which ſerves to faſten it to the plough.

As the long knives uſed by us in the cutting of books or papers are apt to jump in the cutting thick books, the Dutch are ſaid to uſe circular knives with an edge all round; which not only cut more ſteadily, but laſt longer without grinding.

Various other preſſes are uſed in different arts and manufactures; but it does not ſeem neceſſary to give particular deſcriptions of any others, except the preſs uſed in printing of books, and the rolling preſs uſed in copper-plate printing.

The common PRINTING-*preſs* repreſented in plate XXIII. is a curious and rather complex machine. The body conſiſts of two ſtrong cheeks, *a*, *a*, ſtanding perpendicularly, and joined together by four croſs-pieces; the cap *b*, and the head *c*, which is moveable, being partly ſuſtained by two iron pins or long ſcrew-bolts that paſs the cap; the till or ſhelf *d d*, by which the ſpindle and its apparatus are kept in their proper poſition; and the winter *e*, which bears the carriage, and ſuſtains the effort of the preſs beneath. The ſpindle *f* is an upright piece of iron pointed with ſteel, having a male ſcrew, which goes into the female one in the head about four inches. Through the eye *g* of this ſpindle is faſtened the bar *k*, by which the preſſman makes the impreſſion. The ſpindle paſſes through a hole in the middle of the till; and its point works into a braſs pan or nut, ſupplied with oil, which is fixed to an iron plate let into the top of the platen. The body of the ſpindle is ſuſtained in the centre of an open frame of poliſhed iron, 1, 1, 2, 2, 3, 3, fixed to it in ſuch a manner as, without obſtructing its free play, to keep it in a ſteady direction; and at the ſame time to ſerve for ſuſpending the platen. This frame conſiſts of two parts; the upper called the *garter*, 1, 1; the under called the *crane*, 2, 2. These are connected together by two ſhort legs or bolts, 3, 3; which being fixed below in the two ends of the crane, paſs upward through two holes in the till, and are received at top into two eyes at the ends of the garter, where they are ſecured by ſcrews. The carriage *l l* is placed a foot below the platen, having its fore-part ſupported by a prop called the *fore-ſtay*, while the other reſts on the winter. On this carriage, which ſuſtains the plank, are nailed two long iron bars or ribs; and on the plank are nailed ſhort pieces of iron or ſteel called *cramp-irons*, equally tempered with the ribs, and which ſlide upon them when the plank is turned in or out. Under the carriage is fixed a long piece of iron called the *ſpit*, with a double wheel in the middle, round which leather girts are faſtened, nailed to each end of the plank: and to the outſide of the ſpit is fixed a rounce *m*, or handle, to turn round the wheel. Upon the plank is a ſquare frame or coffin, in which is incloſed a poliſhed ſtone on which the form *n* is laid; at the end of the coffin are three frames, viz. the two tympans and friſket: the tympans *o* are ſquare, and made of three ſlips of very thin wood, and at the top a piece of iron ſtill thinner; that called the *outer tympan* is faſtened with hinges to the coffin: they are both covered with parchment; and between the two are placed blankets, which are neceſſary to take off the impreſſion of the letters upon the paper. The friſket *p* is a ſquare frame of thin iron, faſtened with hinges to the tympan: it is covered with paper cut in the neceſſary places, that the ſheet, which is put between the friſket and the great or outward tympan, may receive the ink, and that nothing may hurt the margins. To regulate the margins, a ſheet of paper is faſtened upon this tympan, which is called the *tympan ſheet;* and on each ſide is fixed an iron point, which makes two holes in the ſheet, which is to be placed on the ſame points when the impreſſion is to be made on the other ſide. In preparing the preſs for working, the parchment which covers the outer tympan is wetted till it is very ſoft, in order to render the impreſſion more equable; the blankets are then put in, and ſecured from ſlipping by the inner tympan: then, while one preſſman is beating the letter with the balls covered with ink taken from the ink-block, the other perſon places a ſheet of white paper on the tympan ſheet; turns down the friſket upon it, to keep the paper clean and prevent its ſlipping; then, bringing the tympans upon the form, and turning the rounce, he brings the form with the ſtone, &c. weighing about 300 lbs.

weight, under the platen; pulls with the bar, by which means the platen preſſes the blankets and paper cloſe upon the letter, whereby half the form is printed; then eaſing the bar, he draws the form ſtill forward; gives a ſecond pull, and letting go the bar, turns back the form, takes up the tympans and friſket, takes out the printed ſheet, and lays on a freſh one; and this is repeated till he has taken off the impreſſion upon the full number of ſheets the edition is to conſiſt of. One ſide of the ſheet being thus printed, the form for the other is laid upon the preſs, and worked off in the ſame manner.

The *Rolling*-PRESS uſed in copper-plate printing, is repreſented in fig. 3 pl. XV. This machine, like the common preſs, may be divided into two parts, the *body* and *carriage*, analogous to thoſe in the other.

The body conſiſts of two cheeks PP of different dimenſions, ordinarily about four feet and a half high, a foot thick, and two and a half apart, joined at top and bottom by croſs pieces. The cheeks are placed perpendicularly on a wooden ſtand or foot, LM, horizontally placed, and ſuſtaining the whole preſs. From the foot likewiſe riſe four other perpendicular pieces, *c*, *c*, *c*, *c*, joined by other croſs or horizontal ones *d*, *d*, *d*, which may be conſidered as the carriage of the preſs, as ſerving to ſuſtain a ſmooth, even plank, HIK, about four feet and a half long, two feet and a half broad, and an inch and a half thick; upon which the engraven plate is to be placed. Into the cheeks go two wooden cylinders of rollers DE, FG, about ſix inches in diameter, borne up at each end by the cheeks, whoſe ends, which are leſſened to about two inches diameter, and called *trunnions*, turn in the cheeks between two pieces of wood, in form of half-moons, lined with poliſhed iron, to facilitate the motion. The ſpace in the half-moons, left vacant by the trunnion, is filled with paper, paſtebboard, &c. that they may be raiſed and lowered at diſcretion; ſo as only to leave the ſpace between them neceſſary for the paſſage of the plank charged with the plate, paper, and blankets. Laſtly, to one of the trunnions of the upper roller is faſtened a croſs, conſiſting of two levers AB, or pieces of wood, traverſing each other. The arms of this croſs ſerve in lieu of the handle of the common preſs; giving a motion to the upper roller, and that to the under one; by which means the plank is protruded, or paſſed between them.

The practice of printing from copper-plates is nearly as follows. The workmen take a ſmall quantity of the ink, on a rubber made of linen rags, ſtrongly bound about each other, and with this ſmear the whole face of the plate as it lies on a grate over a charcoal fire. The plate being ſufficiently inked, they firſt wipe it over with a foul rag, then with the palm of their left hand, and then with that of the right; and to dry the hand and forward the wiping, they rub it from time to time in whiting. The addreſs of the workmen conſiſts in wiping the plate perfectly clean, without taking the ink out of the engraving. The plate thus prepared is laid on the plank of the preſs; over the plate is laid the paper, firſt well moiſtened, to receive the impreſſion; and over the paper two or three folds of flannel. Things being thus diſpoſed, the arms of the croſs are pulled, and by that means the plate with its furniture is paſſed through between the rollers, which pinching very ſtrongly, yet equally, preſſes the moiſtened paper into the ſtrokes of the engraving, whence it licks out the ink, and receives the required impreſſion.

PRESSURE ENGINES for raiſing water by the preſſure and deſcent of a column incloſed in a pipe, have been lately erected in different parts of this country. The principle now adverted to was adopted in ſome machinery executed in France about 1731 (ſee Belidor de Arch. Hydraul. lib. iv. ch. 1.), and was likewiſe adopted in Cornwall about forty years ago. But the preſſure engine of which we are about to give a particular deſcription, is the invention of Mr. R. Trevithack, who probably was not aware that any thing at all ſimilar had been attempted before. This engine, a ſection of which, on a ſcale of a quarter of an inch to a foot, is ſhewn in pl. XXIII. was erected about ſix years ago at the Druid Copper Mine, in the pariſh of Illogan, near Truro. AB repreſents a pipe ſix inches in diameter, through which water deſcends from the head to the place of its delivery to run off by an adit at S, through a fall of 34 fathom in the whole; that is to ſay, in a cloſe pipe down the ſlope of a hill 200 fathoms long, with 26 fathoms fall; then perpendicularly ſix fathoms, till it arrives at B, and thence through the engine from B to S two fathoms. At the turn B the water enters into a chamber C, the lower part of which terminates in two braſs cylinders four inches in diameter; in which two plugs or piſtons of lead, D and E, are capable of moving up and down by their piſton rods, which paſs through a cloſe packing above, and are attached to the extremities of a chain leading over and properly attached to the wheel Q, ſo that it cannot ſlip.

The leaden pieces D and E are caſt in their places, and have no packing whatever. They move very eaſily; and if at any time they ſhould become looſe, they may be ſpread out by a few blows with a proper inſtrument, without taking them out of their place. On the ſides of the two braſs cylinders, in which D and E move, there are ſquare holes communicating towards F and G, which is an horizontal trunk or ſquare pipe, four inches wide and three inches deep. All the other pipes G, G, and R, are ſix inches in diameter, except the principal cylinder wherein the piſton H moves; and this cylinder is ten inches in diameter, and admits a nine-foot ſtroke, though it is here delineated as if the ſtroke were only three-foot.

The piſton-rod works through a ſtuffing-box above, and is attached to MN, which is the pit-rod, or a perpendicular piece divided into two, ſo as to allow its alternate motion up and down and leave a ſpace between, without touching the fixed apparatus or great cylinder. The pit-rod is prolonged down into the mine, where it is employed to work the pumps, or if the engine were applied to mill-work, or any other uſe, this rod would form the communication of the firſt mover.

KL is a tumbler or tumbling-bob, capable of being moved on the gudgeons V, from its preſent poſition to another, in which the weight L ſhall hang over with the ſame inclination on the oppoſite ſide of the perpendicular, and conſequently the end K will then be as much elevated as it is now depreſſed.

The pipe RS has its lower end immerſed in a ciſtern, by which means it delivers its water without the poſſibility of the external air introducing itſelf; ſo that it conſtitutes a torricellian column or water barometer, and renders the whole column from A to S effectual: as we ſhall ſee in our view of the operation.

The operation. Let us ſuppoſe the lower bar KV of the tumbler to be horizontal, and the rod PO ſo ſituated, as that the plugs or leaden piſtons D and E ſhall lie oppoſite to each other, and ſtop the water-ways G and F. In this ſtate of the engine, though each of theſe piſtons is preſſed by a force equivalent to more than a thouſand pounds, they will remain motionleſs, becauſe theſe actions being contrary to each other, they are conſtantly in equilibrio. The great piſton H being here ſhewn as at the bottom of its cylinder, the tumbler is to be thrown by hand into the poſition here delineated. Its action upon OP, and conſequently upon the wheel Q, draws up the plug D, and depreſſes E, ſo that the water-way G becomes open from AB, and that of F to the pipe R: the water conſequently deſcends from A to C; thence to G G G, until it acts beneath the piſton H. This preſſure raiſes the piſton, and if there be any water above the piſton, it cauſes it to riſe and paſs through F into R. During the riſe of the piſton (which carries the pit-rod MN along with it), a ſliding block of wood I, fixed to this rod, is brought into contact with the tail K of the tumbler, and raiſes it to the horizontal poſition, beyond which it overſets by the acquired motion of the weight L.

The mere riſe of the piſton, if there were no additional motion in the tumbler, would only bring the two plugs D and E to the poſition of reſt, namely to cloſe G and F, and then the engine would ſtop; but the fall of the tumbler carries the plug D downwards quite clear of the hole F, and the other plug E upwards, quite clear of the hole G. Theſe motions require no conſumption of power, becauſe the plugs are in equilibrio, as was juſt obſerved.

In this new ſituation the column AB no longer communicates with G, but acts through F upon the upper part of the piſton H, and depreſſes it; while the contents of the great cylinder beneath that piſton are driven out through G G G, and paſs through the opening at E into R. It may be obſerved, that the column which acts againſt the piſton is aſſiſted by the preſſure of the atmoſphere, rendered active by the column of water hanging in R, to which that aſſiſting preſſure is equivalent, as has already been noticed.

When the piſton has deſcended through a certain length, the ſlide or block at T, upon the pit-rod, applies againſt the tail K of the tumbler, which it depreſſes, and again overſets; producing once more the poſition of the plugs DE, here delineated, and the conſequent aſcent of the great piſton H, as before deſcribed. The aſcent produces its former effect on the tumbler and plugs; and in this manner it is evident that the alternations will go on without limit: or until the manager ſhall think fit to place the tumbler and plugs DE in the poſitions of reſt; namely, ſo as to ſtop the paſſages F and G.

The length of the ſtroke may be varied by altering the poſitions of the pieces T and I, which will ſhorten the ſtroke the nearer they are together; as in that caſe they will ſooner alternate upon the tail K.

As the ſudden ſtoppage of the deſcent of the column AB, at the inſtant when the two plugs were both in the water-way, might jar and ſhake the apparatus, thoſe plugs are made half an inch ſhorter than the depth of the ſide holes; ſo that in that caſe the water can eſcape directly through both the ſmall cylinders to R. This gives a moment of time for the generation of the contrary motion in the piſton and the water in G G G, and greatly deadens the concuſſion which might elſe be produced.

Some former attempts to make preſſure engines upon the principle of the ſteam-engine have failed; becauſe water, not being elaſtic, could not be made to carry the piſton onwards a little, ſo as completely to ſhut one ſet of valves and open another. In the preſent judicious conſtruction, the tumbler performs the office of the expanſive force of ſteam at the end of the ſtroke.

Mr. Boſwell ſuggeſts, as a conſiderable improvement, that the action of this engine ſhould be made elaſtic by the addition of an air-chamber, on the ſame principle as that uſed in fire-engines; this, he thinks, might be beſt effected by making the piſton hollow, with a ſmall orifice in the bottom, and of a larger ſize, to ſerve for this purpoſe, as the ſpring of the air would then act both on the upward and downward preſſure of the water. *Nich. Jour.* N. S. vols. i. ii.

PULLEY, one of the ſimple machines, or, as they are commonly called, *mechanical powers*: its theory is laid down in arts. 148—151, 267, &c. of our firſt volume. The preſent article is introduced for the purpoſe of mentioning ſome ingenious practical combinations of pulleys, in addition to thoſe exhibited in pl. VI. vol. i.

The uſual methods of arranging pulleys in their blocks may be reduced to two. The firſt conſiſts in placing them one by the ſide of another upon the ſame pin: the other, in placing them directly under one another upon ſeparate pins. Each of theſe methods however is liable to inconvenience; and Mr. Smeaton, to avoid the impediments to which theſe combinations are ſubject, propoſes to combine theſe two methods in one.

A very conſiderable improvement in the conſtruction of pulleys has been made by Mr. James White, who obtained a patent for his invention, of which he gives the following deſcription. Fig. 6. pl. XIX. ſhews the machine, conſiſting of two pulleys, Q and R, one fixed and the other moveable. Each of theſe has ſix concentric grooves capable of having a line put round them, and thus acting like as many different pulleys, having diameters equal to thoſe of the grooves. Suppoſing then each of the grooves to be a diſtinct pulley, and that all their diameters were equal, it is evident that if the weight 144 were to be raiſed by pulling at S till the pulleys touch each other, the firſt pulley muſt receive the length of line as many times as there are parts of the line hanging between it and the lower pulley. In the preſent caſe there are 12 lines *b*, *d*, *f*, &c. hanging between the two pulleys, formed by its revolution about the ſix upper and lower grooves. Hence, as much line muſt paſs over the uppermoſt pulley as is equal to twelve times the diſtance of the two. But, from an inſpection of the figure, it is plain that the ſecond pulley cannot receive the full quantity of line by as much as is equal to the diſtance betwixt it and the firſt. In like manner, the third pulley receives leſs than the firſt by as much as is the diſtance between the firſt and third; and ſo on to the laſt, which receives only one-twelfth of the whole. For this receives its ſhare of line *n* from a fixed point in the upper frame, which gives it nothing; while all the others in the ſame frame receive the line partly by turning to meet it, and partly by the line coming to meet them.

Suppoſing now theſe pulleys to be equal in ſize, and to move freely as the line determines them, it appears evident, from the nature of the ſyſtem, that the number of their revolutions, and conſequently their velocities, muſt be in proportion to the number of ſuſpending parts that are between the fixed point above mentioned and each pulley reſpectively. Thus the outermoſt pulley would go twelve times round in the time that the pulley under which the part *n* of the line, if equal to it, would revolve only once; and the intermediate times and velocities would be a ſeries of arithmetical proportionals, of which, if the firſt number were 1, the laſt would always be equal to the whole number of terms. Since then the revolutions of equal and diſtinct pulleys are meaſured by their velocities, and that it is poſſible to find any proportion of velocity on a ſingle body running on a centre, viz. by finding proportionate diſtances from that centre; it follows, that if the diameters of certain grooves in the ſame ſubſtance be exactly adapted to the above ſeries (the line itſelf being ſuppoſed inelaſtic, and of no magnitude), the neceſſity of uſing ſeveral pulleys in each frame will be obviated, and with that ſome of the inconveniences to which the uſe of the pulley is liable.

In the figure referred to, the coils of rope by which the weight is ſupported, are repreſented by the lines *a*, *b*, *c*, &c.: *a* is the line of traction, commonly called the fall, which paſſes over and under the proper grooves, until it is faſtened to the upper frame juſt above *n*. In practice, however, the grooves are not arithmetical proportionals, nor can they be ſo; for the diameter of the rope employed muſt in all caſes be deducted from each term; without which the ſmaller grooves, to which the ſaid diameter bears a larger proportion than to the larger ones, will tend to riſe and fall faſter than they, and thus introduce worſe defects than thoſe which they were intended to obviate.

The principal advantage of this kind of pulley is, that it deſtroys lateral friction, and that kind of ſhaking motion which is ſo inconvenient in the common pulley. And leſt (ſays Mr. White) this circumſtance ſhould give the idea of weakneſs, I would obſerve, that to have pins for the pulleys to run on, is not the only nor perhaps the beſt method; but that I ſometimes uſe centres fixed to the pulleys, and revolving on a very ſhort bearing in the ſide of the frame, by which ſtrength is increaſed, and friction very much diminiſhed; for to the laſt moment the motion of the pulley is perfectly circular: and this very circumſtance is the cauſe of its not wearing out in the centre as ſoon as it would, aſſiſted by the ever-increaſing irregularities of a gullied bearing. Theſe pulleys, when well executed, apply to jacks and other machines of that nature with peculiar advantage, both as to the time of going and their own durability; and it is poſſible to produce a ſyſtem of pulleys of this kind of ſix or eight parts only, and adapted to the pocket, which, by means of a ſkain of ſewing ſilk, or a clue of common thread, will raiſe upwards of a hundred weight.

The friction of the pulley is now reduced to nothing, as it were, by Mr. Garnett's ingenious patent friction-rollers, which produce a great ſaving of labour and expence, as well as in the wear of the machine, both when applied to pulleys and to the axles of wheel-carriages. His general principle is this; between the axle and nave, or centre pin and box, a hollow ſpace is left, to be filled up by ſolid equal rollers nearly touching each other. Theſe are furniſhed with axles inſerted into a circular ring at each end, by which their relative diſtances are preſerved; and they are kept parallel by means of wires faſtened to the rings between the rollers, and which are rivetted to them.

PUMP, an hydraulic machine for raiſing water by the preſſure of the atmoſphere.

The moſt important and certain part of the theory of pumps has been laid down in arts. 524—538, of our firſt volume: and the conſtruction of two or three kinds has been already deſcribed in this volume under the articles CENTRIFUGAL *machine*, FIRE-*engine*, FORCER, and HYDRAULIC *engines*. A few other uſeful, yet not complex, pumps, will be deſcribed in the preſent article: and ſome account will be added of the moſt ingenious piſtons and valves.

1. A modification of the ſucking-pump which has been much recommended, is exhibited in plate XXV. fig. 17. Here the ſuction-pipe CO comes up through a ciſtern KMNL deeper or longer than the intended ſtroke of the piſton, and has a valve C at top. The piſton, or what acts in lieu of it, is a tube AHGB, open at both ends, and of a diameter ſomewhat larger than that of the ſuction-pipe. The interval between them is filled up at HG by a ring or belt of ſoft leather, which is faſtened to the outer tube, and moves up and down with it, ſliding along the ſmoothly poliſhed ſurface of the ſuction-pipe with very little friction. There is a valve I on the top of this piſton, opening upwards. Water is poured into the outer ciſtern.

The outer cylinder or piſton being drawn up from the bottom, there is a great rarefaction of the air which was between them, and the atmoſphere preſſes the water up through the ſuction-pipe to a certain height; for the valve I keeps ſhut by the preſſure of the atmoſphere and its own weight. Puſhing down the piſton cauſes the air, which had expanded from the ſuction-pipe into the piſton, to eſcape through the valve I; drawing it up a ſecond time allows the atmoſphere to preſs more water into the ſuction-pipe, to fill it, and alſo part of the piſton. When this is puſhed down again, the water which had come through the valve C is now forced out through the valve I into the ciſtern KMNL, and now the whole is full of water. When, therefore, the piſton is drawn up, the water follows, and fills it, if not 33 feet above the water in the ciſtern; and when it is puſhed down again, the water which filled the piſton is all thrown out into the ciſtern; and after this it delivers its full contents of water every ſtroke. The water in the ciſtern KMNL effectually prevents the entrance of any air between the two pipes; ſo that a very moderate compreſſion of the belt of ſoft leather at the mouth of the piſton cylinder is ſufficient to make all perfectly tight.

It might be made differently. The ring of leather might be faſtened round the top of the inner cylinder at DE, and ſlide on the inſide of the piſton cylinder: but the firſt form is moſt eaſily executed. Muſchenbroeck has given a figure of this pump in his large ſyſtem of natural philoſophy, and ſpeaks very highly of its performance. But we do not ſee any advantage which it poſſeſſes over the common ſucking-pump. He indeed ſays that it is without friction, and makes no mention of the ring of leather between the two cylinders. Such a pump will raiſe water extremely well to a ſmall height, and it ſeems to have been a model only which he had examined: but if the ſuction-pipe be long, it will by no means do without the leather; for on drawing up the piſton, the water of the upper ciſtern will riſe between the pipes, and fill the piſton, and none will come up through the ſuction-pipe.

We may take this opportunity of obſerving, that the many ingenious contrivances of pumps without friction are of little importance in great works; becauſe the friction which is completely ſufficient to prevent all eſcape of water in a well-conſtructed pump is but a very trifling part of the whole force. In the great pumps which are uſed in mines, and are worked by a ſteam-engine, it is very uſual to make the piſtons and valves without any leather whatever. The working barrel is bored truly cylindrical, and the piſton is made of metal of a ſize that will juſt paſs along it without ſticking. When this is drawn up with the velocity competent to a properly loaded machine, the quantity of water which eſcapes round the piſton is inſignificant. The piſton is made without leathers, not to avoid friction, which is alſo inſignificant in ſuch works; but to avoid the neceſſity of frequently drawing it up for repairs through ſuch a length of pipes.

2. If a pump abſolutely without friction is wanted, the following ſeems preferable for ſimplicity and performance to any we have ſeen, when made uſe of in proper ſituations. Let NO (fig. 18.) be the ſurface of the water in the pit, and K the place of delivery. The pit muſt be as deep in water as from K to NO. ABCD is a wooden trunk, round or ſquare, open at both ends, and having a valve P at the bottom. The top of this trunk muſt be on a level with K, and has a ſmall ciſtern EADF. It alſo communicates laterally with a riſing pipe GHK, furniſhed with a valve at H opening upwards. LM is a beam of timber ſo fitted to the trunk as to fill it without ſticking, and is of at leaſt equal length. It hangs by a chain from a working beam, and is loaded on the top with weights exceeding that of the column of water which it diſplaces. Now ſuppoſe this beam allowed to deſcend from the poſition in which it is drawn in the figure; the water muſt riſe all around it, in the crevice which is between it and the trunk, and alſo in the riſing pipe; becauſe the valve P ſhuts, and H opens; ſo that when the plunger has got to the bottom, the water will ſtand at the level of K. When the plunger is again drawn up to the top by the action of the moving power, the water ſinks again in the trunk, but not in the riſing pipe, becauſe it is ſtopped by the valve H. Then allowing the plunger to deſcend again, the water muſt again riſe in the trunk to the level of K, and it muſt now flow out at K; and the quantity diſcharged will be equal to the part of the beam below the ſurface of the pit-water, deducting the quantity which fills the ſmall ſpace between the beam and the trunk. This quantity may be reduced almoſt to nothing; for if the inſide of the trunk and the outſide of the beam be made tapering, the beam may be let down till they exactly fit; and as this may be done in ſquare work, a good workman can make it exceedingly accurate. But in this caſe, the lower half of the beam and trunk muſt not taper; and this part of the trunk muſt be of ſufficient width round the beam to allow free paſſage into the riſing pipe. Or, which is better, the riſing pipe muſt branch off from the bottom of the trunk. A diſcharge may be made from the ciſtern EADF, ſo that as little water as poſſible may deſcend along the trunk when the piſton is raiſed.

One great excellence of this pump is, that it is perfectly free from all the deficiencies which in common pumps reſult from want of being air-tight. Another is, that the quantity of water raiſed is preciſely equal to the power expended; for any want of accuracy in the work, while it occaſions a diminution of the quantity of water diſcharged, makes an equal diminution in the weight which is abſolutely neceſſary for puſhing down the plunger. We have ſeen a machine conſiſting of two ſuch pumps ſuſpended from the arms of a long beam, the upper ſide of which was formed into a walk with a rail on each ſide. A man ſtood on one end till it got to the bottom, and then walked gently up to the other end, the inclination being about twenty-five degrees at firſt, but gradually diminiſhed as he went along, and changed the load of the beam. By this means he made the other end go to the bottom, and ſo on alternately, with the eaſieſt of all exertions, and what we are moſt fitted for by our ſtructure. With this machine, a very feeble old man, weighing 110 pounds, raiſed 7 cubic feet of water 11½ feet high in a minute, and continued working 8 or 10 hours every day. A ſtout young man, weighing nearly 135 pounds, raiſed 8⅓ to the ſame height; and when he carried 30 pounds, conveniently flung about him, he raiſed 9¼ feet of this height, working 10 hours a-day without fatiguing himſelf. This exceeds Deſagulier's maximum of a hogſhead of water 10 feet high in a minute, in the proportion of 9 to 7 nearly. It is limited to very moderate heights; but in ſuch ſituations it is very effectual. Belidor applies a nearly ſimilar contrivance to the working of double pumps in general.

3. The moſt ingenious contrivance of a pump without friction is that of Mr. Haſkins, deſcribed in Phil. Tranſ. No. 370, and called by him the QUICKSILVER PUMP. Its conſtruction and mode of operation are pretty complicated; but the following preliminary obſervations will, we hope, render it abundantly plain.

Let there (fig. 19.) be a cylindrical iron pipe, about ſix feet long, open at top, alſo another cylinder, connected with it at bottom, and of ſmaller diameter. It may either be ſolid, or, if hollow, it muſt be cloſe at top. Let a third iron cylinder, of an intermediate diameter, be made to move up and down between the other two without touching either, but with as little interval as poſſible. This middle cylinder communicates, by means of the pipe AB, with the upright pipe FE, having valves C and D (both opening upwards) adjoining to the pipe of communication. Suppoſe the outer cylinder ſuſpended by chains from the end of a working beam, and let mercury be poured into the interval between the three cylinders till it fills the ſpace to about three-fourths of their height. Alſo ſuppoſe that the lower end of the pipe FE is immerſed into a ciſtern of water, and that the valve D is leſs than 33 feet above the ſurface of this water.

Now ſuppoſe a perforation made ſomewhere in the pipe AB, and a communication made with an air-pump. When the air-pump is worked, the air contained in CE, in AB, and in the ſpace between the inner and middle cylinders, is rarefied, and is abſtracted by the air-pump; for the valve D immediately ſhuts. The preſſure of the atmoſphere will cauſe the water to riſe in the pipe CE, and will cauſe the mercury to riſe between the inner and middle cylinders, and ſink between the outer and middle cylinders. Let us ſuppoſe mercury 12 times heavier than water: then for every foot that the water riſes in EC, the level between the outſide and inſide mercury will vary an inch; and if we ſuppoſe DE to be 30 feet, then if we can rarefy the air ſo as to raiſe the water to D, the outſide mercury will be depreſſed to *q*, *r*, and the inſide mercury will have riſen to *s*, *t*, *s q* and *t r* being about 30 inches. In this ſtate of things, the water will run over by the pipe BA, and every thing will remain nearly in this poſition. The columns of water and mercury balance each other, and balance the preſſure of the atmoſphere.

While things are in this ſtate of equilibrium, if we allow the cylinders to deſcend a little, the water will riſe in the pipe FE, which we may now conſider as a ſuction-pipe; for by this motion the capacity of the whole is enlarged, and therefore the preſſure of the atmoſphere will ſtill keep it full, and the ſituation of the mercury will again be ſuch that all ſhall be in equilibrio. It will be a little lower in the inſide ſpace and higher in the outſide.

Taking this view of things, we ſee clearly how the water is ſupported by the atmoſphere at a very conſiderable height. The apparatus is analogous to a ſyphon which has one leg filled with water and the other with mercury. But it was not neceſſary to employ an air-pump to fill it. Suppoſe it again empty, and all the valves ſhut by their own weight. Let the cylinders deſcend a little. The capacity of the ſpaces below the valve D is enlarged, and therefore the included air is rarefied, and ſome of the air in the pipe CE muſt diffuſe itſelf into the ſpace quitted by the inner cylinder. Therefore the atmoſphere will preſs ſome water up the pipe FE, and ſome mercury into the inner ſpace between the cylinders. When the cylinders are raiſed again, the air which came from the pipe CE would return into it again, but is prevented by the valve C.—Raiſing the cylinders to their former height would compreſs this air; it therefore lifts the valve D, and eſcapes. Another depreſſion of the cylinders will have a ſimilar effect. The water will riſe higher in FC, and the mercury in the inner ſpace; and then, after repeated ſtrokes the water will paſs the valve C, and fill the whole apparatus, as the air-pump had cauſed it to do before. The poſition of the cylinders, when things are in this ſituation, is repreſented in fig. 20. the outer and inner cylinder in their loweſt poſition having deſcended about 30 inches. The mercury in the outer ſpace ſtands at *q*, *r*, a little above the middle of the cylinders, and the mercury in the inner ſpace is near the top *t s* of the inner cylinder. Now let the cylinders be drawn up. The water above the mercury cannot get back again through the valve C, which ſhuts by its own weight. We therefore attempt to compreſs it; but the mercury yields, and deſcends in the inner ſpace, and riſes in the outer till both are quickly on a level, about the height *v v*. If we continue to raiſe the cylinders, the compreſſion forces out more mercury, and it now ſtands lower in the inner than in the outer ſpace. But that there may be ſomething to balance this inequality of the mercurial columns, the water goes through the valve D, and the equilibrium is reſtored when the height of the water in the pipe ED above the ſurface of the internal mercury is 12 times the difference of the mercurial columns (on the former ſuppoſition of ſpecific gravity). If the quantity of water be ſuch as to riſe two feet in the pipe ED, the mercury in the outer ſpace will be two inches higher than that in the inner ſpace. Another depreſſion of the cylinders will again enlarge the ſpace within the apparatus, the mercury will take the poſition of fig. 19. and more water will come in. Raiſing the cylinders will ſend this water four feet up the pipe ED, and the mercury will be four inches higher in the inner than in the outer ſpace. Repeating this operation, the water will be raiſed ſtill higher in DE; and this will go on till the mercury in the outer ſpace reaches the top of the cylinder; and this is the limit of the performance. The dimenſions with which we ſet out will enable the machine to raiſe the water about 30 feet in the pipe, ED; which, added to the 30 feet of CF, makes the whole height above the pit-water 60 feet. By making the cylinders longer, we increaſe the height of FD. This machine muſt be worked with great attention, and but ſlowly; for at the beginning of the forcing ſtroke the mercury very rapidly ſinks in the inner ſpace and riſes in the outer, and will daſh out and be loſt. To prevent this as much as poſſible, the outer cylinder terminates in a ſort of cup or diſh, and the inner cylinder ſhould be tapered at the top.

The machine is exceedingly ingenious and refined; and there is no doubt but that its performance will exceed that of any other pump which raiſes the water to the ſame height, becauſe friction is completely avoided, and there can be no want of tightneſs of the piſton. But this is all its advantage; and from what has been obſerved, it is but trifling. The expence would be enormous; for with whatever care the cylinders are made, the interval between the inner and outer cylinders muſt contain a very great quantity of mercury. The middle cylinder muſt be made of iron plate, and muſt be without a ſeam, for the mercury would diſſolve every ſolder. For ſuch reaſons, it has never come into general uſe. But it would have been unpardonable to have omitted the deſcription of an invention which is ſo original and ingenious; and there are ſome occaſions where it may be of great uſe, as in nice experiments for illuſtrating the theory of hydraulics, it would give the fineſt piſtons for meaſuring the preſſures of water, in pipes, &c.

The following pump, without friction, may be conſtructed in a variety of ways by any common carpenter, without the aſſiſtance of the pump-maker, or plumber, and will be very effective for raiſing a great quantity of water to ſmall heights, as in draining marſhes, marle pits, quarries, &c. or even for the ſervice of a houſe.

4. ABCD (pl. XXV. fig. 21.) is a ſquare trunk of carpenter's work open at both ends, and having a little ciſtern and ſpout at top. Near the bottom there is a partition made of board, perforated with a hole E, and covered with a clack. *ffff* repreſent a long cylindrical bag made of leather or of double canvas, with a fold of thin leather, ſuch as ſheepſkin, between the canvas bags. This is firmly nailed to the board E with ſoft leather between. The upper end of this bag is fixed on a round board having a hole and valve F. This board may be turned in the lathe with a groove round its edge, and the bag faſtened to it by a cord bound tight round it. The fork of the piſton-rod FG is firmly fixed into this board; the bag is kept diſtended by a number of wooden hoops or rings of ſtrong wire *ff*, *ff*, *ff*, &c. put into it at a few inches diſtance from each other. It will be proper to connect theſe hoops before putting them in, by three or four cords from top to bottom, which will keep them at their proper diſtances. Thus will the bag have the form of a barber's bellows powder-puff. The diſtance between the hoops ſhould be about twice the breadth of the rim of the wooden ring to which the upper valve and piſton-rod are fixed.

Now let this trunk be immerſed in the water. It is evident that if the bag be ſtretched from the compreſſed form which its own weight will give it by drawing up the piſton-rod, its capacity will be enlarged, the valve F will be ſhut by its own weight, the air in the bag will be rarefied, and the atmoſphere will preſs the water into the bag. When the rod is thruſt down again, this water will come out by the valve F, and fill part of the trunk. A repetition of the operation will have a ſimilar effect; the trunk will be filled, and the water will at laſt be diſcharged by the ſpout.

Here is a pump without friction, and perfectly tight. For the leather between the folds of canvas renders the bag impervious both to air and water. And the canvas has very conſiderable ſtrength. We know from experience that a bag of ſix inches diameter, made of ſail-cloth No. 3. with a ſheepſkin between, will bear a column of 15 feet of water, and ſtand ſix hours work per day for a month without failure, and that the pump is conſiderably ſuperior in effect to a common pump of the ſame dimenſions. We muſt only obſerve, that the length of the bag muſt be three times the intended length of the ſtroke; ſo that when the piſton-rod is in its higheſt poſition, the angles or ridges of the bag may be pretty acute. If the bag be more ſtretched than this, the force which muſt be exerted by the labourer becomes much greater than the weight of the column of water which he is raiſing. If the pump be laid aſlope, which is very uſual in theſe occaſional and haſty drawings, it is neceſſary to make a guide for the piſton-rod within the trunk, that the bag may play up and down without rubbing on the ſides, which would quickly wear it out.

The experienced reader will ſee that this pump is very like that of Goſſet and De la Deuille, deſcribed by Belidor, vol. ii. p. 120, and moſt writers on hydraulics. It would be ſtill more like it, if the bag were on the under ſide of the partition E, and a valve placed further down the trunk. But we think that our form is greatly preferable in point of ſtrength. When in the other ſituation, the column of water lifted by the piſton tends to *burſt* the bag, and this with a great force, as the intelligent reader well knows. But in the form recommended here, the bag is *compreſſed*, and the ſtrain on each part may be made much leſs than that which tends to burſt a bag of ſix inches diameter. The nearer the rings are placed to each other the ſmaller will the ſtrain be.

The ſame bag-piſton may be employed for a forcing-pump, by placing it below the partition, and inverting the valve; and it will then be equally ſtrong, becauſe the reſiſtance in this caſe too will act by compreſſion.

5. An ingenious variation in the conſtruction of the ſucking-pump, is that with two piſton-rods in the ſame barrel, invented by Mr. Walter Taylor, of Southampton. A vertical ſection of this pump is given in fig. 1. pl. XXIV. The piſton-rods have racks at their upper parts working on the oppoſite ſides of a pinion, and kept to their proper poſitions by friction-rollers. The valves uſed in this pump are of three kinds, as ſhewn at *a*, *b*, and *c*. The former is a ſpheric ſegment which ſlides up and down on the piſton-rod, and is brought down by its own weight: the ſecond, *b*, is called the pendulum-valve: and the third, *c*, is

a globe which is raiſed by the riſing water, and falls again by its own weight. Each of theſe valves will diſengage itſelf from chips, ſand, gravel, &c. brought up by the water. In this kind of pump the piſtons may either be put in motion by a handle in the uſual way, or a rope may paſs round the wheel *d e* in a proper groove, the two ends of which, after croſſing at the lower part of the wheel, may be pulled by one man or more on each ſide. A pump of this kind, with a ſeven-inch bore, heaves a ton twenty-four feet high in a minute, with ten men, five only working at a time on each ſide.

6. Another improvement of the common pump has been made by Mr. Todd of Hull. This invention in ſome particulars bears a reſemblance to the ordinary one, but he has contrived to double its powers by the following means:

Having prepared the piſton-cylinder, which may be twelve feet high, he cuts from the bottom thereof about three feet; at the end of the great cylinder he places an atmoſpheric-valve, and to the top of the ſmall cylinder a ſerving-valve. In the bottom of the ſmall cylinder, which contains the ſerving-valve, is inſerted an oblong elliptical curved tube, of equal calibre with the principal cylinder, and the other end is again inſerted in the top of the great cylinder. This tube is divided in the ſame manner as the firſt cylinder, with atmoſpheric and ſerving valves, exactly parallel with the valves of the firſt cylinder. The pump, thus having double valves, produces double effects, which effects may be ſtill further increaſed by extending the dimenſions.

The cylinder is ſcrewed for ſervice on a male tube-ſcrew, which projects from the ſide of a reſervoir or water ciſtern, and is worked by hand.

The piſton-plunger is worked by a toothed ſegment-wheel, ſimilar to the principle of the one uſed in working the chain-pumps of ſhips belonging to the royal navy; and the wheel receives its motion from a hand-winch, which is conſiderably accelerated by a fly-wheel of variable dimenſions, at the oppoſite end.

This pump, in addition to its increaſed powers, poſſeſſes another very great and prominent advantage. By ſcrewing to it the long leather tube and fire-pipe of the common engine, it is in a few minutes converted into an effective fire-engine. Hence, whoever poſſeſſes one may be ſaid to have a convenient domeſtic apparatus againſt fire. Three men can work it; one to turn the winch, another to direct the fire-pipe, and a third to ſupply the water.

7. Double, triple, or quadruple pumps, admit of great variety in their conſtruction, to ſuit different purpoſes. The beſt col-

lection of theſe with which we are acquainted, is to be found in Leupold's *Theatrum Machinarum Hydraulicarum:* ſome in this collection are very ſingular and ingenious, and have particular advantages to ſuit local circumſtances, and give them a preference. The late Mr. Benjamin Martin invented a curious and powerful pump with two piſtons, the friction of which was exceedingly ſmall. An admirable engraving of this pump, by *Lowry*, is given in vol. 20. of Tilloch's Philoſophical Magazine. The triple pump, a ſketch of which may be ſeen in fig. 9. pl. XXIV. is taken from Bockler's *Theatrum Machinarum;* the nature of the machinery by which this pump is worked, will be ſufficiently obvious to any perſon after an inſpection of the figure: the horizontal wheel C, and its ſhaft A, are turned by the capſtan bars B, this wheel drives the pinion D, on the axle of which is the equalizing fly E, and the crank F: the rotatory motion of the crank alternately raiſes and depreſſes the bar G, with the lever H turning on a roller and pivots, and thus works the pump I: at the ſame time the connecting rods K move in like manner the lever M, and work the pump O; and the rods K move the lever N, and work the pump P. If the levers H, M, N, are not ſo contrived that the extremities of each ſhall move through equal ſpaces, the bores of I, O, and P, muſt be made in the inverſe ratio of thoſe ſpaces, otherwiſe one or other of the reſervoirs may be drawn dry; a defect that ſhould be carefully guarded againſt.

8. Our attention may now be directed to ſome of the different forms which may be given to the piſtons and valves of a pump.

The great deſideratum in a piſton is, that while it be as tight as poſſible, it ſhould have as little friction as is conſiſtent with this indiſpenſable quality. The common form, when carefully executed, poſſeſſes theſe properties in an eminent degree. This piſton is a ſort of truncated cone, generally made of wood not apt to ſplit, ſuch as elm or beech. The ſmall end of it is cut off at the ſides, ſo as to form a ſort of arch, by which it is faſtened to the iron rod or ſpear. The two ends of the conical part may be hooped with braſs. This cone has its larger end ſurrounded with a ring or band of ſtrong leather faſtened with nails, or by a copper hoop, which is driven on it at the ſmaller end. The further this band reaches beyond the baſe of the cone, the better; and the whole muſt be of uniform thickneſs all round, ſo as to ſuffer equal compreſſion between the cone and working barrel. The ſeam or joint of the two ends of this band muſt be made very cloſe; but not ſewed or ſtitched together, as that would occaſion bumps or inequalities, which would ſpoil its tightneſs; and no harm can reſult from the want of it, becauſe the two edges will be ſqueezed cloſe together by the compreſſion in the barrel. Nor is it by any means neceſſary that this compreſſion be great: this is a very detrimental error of the pump-makers. It occaſions enormous friction, and deſtroys the very purpoſe which they have in view, viz. rendering the piſton air-tight; for it cauſes the leather to wear through very ſoon at the edge of the cone, and it alſo wears the working barrel. This very ſoon becomes wide in that part which is continually paſſed over by the piſton, while the mouth remains of its original diameter, and it becomes impoſſible to thruſt in a piſton which ſhall completely fill the worn part. Now, a very moderate preſſure is ſufficient for rendering the pump perfectly tight, and a piece of glove leather would be ſufficient for this purpoſe, if looſe or detached from the ſolid cone; for ſuppoſe ſuch a looſe and flexible, but impervious, band of leather put round the piſton, and put into the barrel; and let it even be ſuppoſed that the cone does not compreſs it in the ſmalleſt degree to its internal ſurface. Pour a little water carefully into the inſide of this ſort of cup or diſh; it will cauſe it to ſwell out a little, and apply itſelf cloſe to the barrel all round, and even adjuſt itſelf to all its inequalities. Let us ſuppoſe it to touch the barrel in a ring of an inch broad all round. We can eaſily compute the force with which it is preſſed. It is half the weight of a ring of water an inch deep and an inch broad. This is a trifle, and the friction occaſioned by it not worth regarding; yet this trifling preſſure is ſufficient to make the paſſage perfectly impervious, even by the moſt enormous preſſure of a high column of incumbent water: for let this preſſure be ever ſo great, the preſſure by which the leather adheres to the barrel always exceeds it, becauſe the incumbent fluid has no *preponderating* power by which it can force its way between them, and it muſt inſinuate itſelf preciſely ſo far, that its preſſure on the inſide of the leather ſhall ſtill exceed, and only exceed, the preſſure by which it endeavours to inſinuate itſelf; and thus the piſton becomes perfectly tight with the ſmalleſt poſſible friction. This reaſoning is perhaps too refined for the uninſtructed artiſt, and probably will not perſuade him. To ſuch we would recommend an examination of the piſtons and valves contrived and executed by that artiſt, whoſe ſkill far ſurpaſſes our higheſt conceptions, the all-wiſe Creator of this world. The valves which ſhut up the paſſages of the veins, and this in places where an extravaſation would be followed by inſtant death, are cups of thin membrane, which adhere to the ſides of the channel about half way round, and are detached in the reſt of their circumference. When the blood comes in the oppoſite direction, it puſhes the membrane aſide, and has a paſſage perfectly free. But a ſtagnation of motion allows the tone of the (perhaps) muſcular membrane, to reſtore it to its natural ſhape, and the leaſt *motion* in the oppoſite direction cauſes it inſtantly to clap cloſe to the ſides of the vein, and then no preſſure whatever can force a paſſage. We ſhall recur to this again when deſcribing the various contrivances of valves, &c. What we have ſaid is enough for ſupporting our directions for conſtructing a tight piſton. But we recommend thick and ſtrong leather, while our preſent reaſoning ſeems to render thin leather preferable. If the leather be thin, and the ſolid piſton in any part does not preſs it gently to the barrel, there will be in this part an unbalanced preſſure of the incumbent column of water, which would inſtantly burſt even a ſtrong leather bag; but when the ſolid piſton, covered with leather, exactly fills the barrel, and is even preſſed a little to it, there is no ſuch riſk; and now that part of the leather band which reaches beyond the ſolid piſton performs its office in the completeſt manner. We do not heſitate, therefore, to recommend this form of a piſton, which is the moſt common and ſimple of all, as preferable, when well executed, to many of thoſe more artificial, and frequently very ingenious, conſtructions, which we have met with in the works of the firſt engineers.

Belidor, an author of the firſt reputation, has given the deſcription of a piſton which he highly extols, and is undoubtedly a very good one, conſtructed from principle, and extremely well compoſed.

9. It conſiſts of a hollow cylinder of metal (XXV. fig. 22.) pierced with a number of holes, and having at top a flanch, whoſe diameter is nearly equal to that of the working barrel of the pump. This flanch has a groove round it. There is another flanch below, by which this hollow cylinder is faſtened with bolts to the lower end of the piſton, repreſented in fig. 23. This conſiſts of a plate with a grooved edge ſimilar to AB, and an intermediate plate which forms the ſeat of the valve. The compoſition of this part is better underſtood by inſpecting the figure than by any deſcription. The piſton-rod HL is fixed to the upper plate by bolts through its different branches at G, G. This metal body is then covered with a cylindrical bag of leather, faſtened on it by cords bound round it, filling up the grooves in the upper and lower plates. The operation of the piſton is as follows.

A little water is poured into the pump, which gets paſt the ſides of the piſton, and lodges below in the fixed valve. The piſton being puſhed down dips into this water, and it gets into it by the valve. But as the piſton in deſcending compreſſes the air below it, this compreſſed air alſo gets into the inſide of the piſton, ſwells out the bag which ſurrounds it, and compreſſes it to the ſides of the working-barrel. When the piſton is drawn up again, it muſt remain tight, becauſe the valve will ſhut and keep in the air in its moſt compreſſed ſtate; therefore the piſton muſt perform well during the ſuction. It muſt act equally well when puſhed down again, and acting as a forcer; for, however great the reſiſtance may be, it will affect the air within the piſton to the ſame degree, and keep the leather cloſe applied to the barrel. There can be no doubt therefore of the piſton's performing both its offices completely; but we imagine that the adheſion to the barrel will be greater than is neceſſary: it will extend over the whole ſurface of the piſton, and be equally great in every part of its ſurface; and we ſuſpect that the friction will therefore be very great. We have very high authority for ſuppoſing that the adheſion of a piſton of the common form, carefully made, will be ſuch as will make it perfectly tight; and it is evident that the adheſion of Belidor's piſton will be much greater, and it will be productive of worſe conſequences. If the leather bag be worn through in any one place, the air eſcapes, and the piſton ceaſes to be compreſſed altogether; whereas in the common piſton there will very little harm reſult from the leather being worn through in one place, eſpecially if it project a good way beyond the baſe of the cone. We ſtill think the common piſton preferable.

10. Belidor deſcribes another forcing piſton, which he had executed with ſucceſs, and prefers to the common wooden forcer. It conſiſts of a metal cylinder or cone, having a broad flanch united to it at one end, and a ſimilar flanch which is ſcrewed on the other end. Between theſe two plates are a number of rings of leather ſtrongly compreſſed by the two flanches, and then turned in a lathe like a block of wood, till the whole fits tight, when dry, into the barrel. It will ſwell, ſays he, and ſoften with the water, and withſtand the greateſt preſſures. We cannot help thinking this but an indifferent piſton. When it wears, there is nothing to ſqueeze it to the barrel. It may indeed be taken out and another ring or two of leather put in, or the flanches may be more ſtrongly ſcrewed together: but all this may be done with any kind of piſton; and this has therefore no peculiar merit.

11. The following will, we preſume, appear greatly preferable. ABCD (fig. 24.), is the ſolid wooden or metal block of the piſton; EF is a metal plate, which is turned hollow or diſh-like below, ſo as to receive within it the ſolid block. The piſton-rod goes through the whole, and has a ſhoulder above the plate EF, and a nut H below. Four ſcrew-bolts alſo go through the whole, having their heads ſunk into the block, and

nuts above. The packing, or ſtuffing, as it is termed by the workmen, is repreſented at NO. This is made as ſolid as poſſible, and generally conſiſts of ſoft hempen twine well ſoaked in a mixture of oil, tallow, and roſin. The plate EF is gently ſcrewed down, and the whole is then put into the barrel, fitting it as tight as may be thought proper. When it wears looſe, it may be tightened at any time by ſcrewing down the nuts which cauſe the edges of the diſh to ſqueeze out the packing, and compreſs it againſt the barrel to any degree.

The greateſt difficulty in the conſtruction of a piſton is to give a ſufficient paſſage through it for the water, and yet allow a firm ſupport for the valve, and fixture for the piſton-rod. It occaſions a conſiderable expence of the moving power to force a piſton with a narrow perforation through the water lodged in the working barrel. When we are raiſing water to a ſmall height, ſuch as 10 or 20 feet, the power ſo expended amounts to a fourth part of the whole, if the water-way in the piſton is leſs than one-half of the ſection of the barrel, and the velocity of the piſton two feet per ſecond, which is very moderate. There can be no doubt, therefore, that metal piſtons are preferable, becauſe their greater ſtrength allows much wider apertures.

12. The following piſton, deſcribed and recommended by Belidor, ſeems as perfect in theſe reſpects as the nature of things will allow. We ſhall therefore deſcribe it in the author's own words, as a model which may be adopted with confidence in the greateſt works.

" The body of the piſton is a truncated metal cone CCXX (fig. 25.), having a ſmall fillet at the greater end. Fig. 26. ſhows the profile, and fig. 27, the plan of its upper baſe; where appears a croſs bar DD, pierced with an oblong mortiſe E for receiving the tail of the piſton-rod. A band of thick and uniform leather AA (fig. 26. and 28.) is put round this cone, and ſecured by a braſs hoop BB firmly driven on its ſmaller end, where it is previouſly made thinner to give room for the hoop.

" This piſton is covered with a leather valve, fortified with metal plates GG (fig. 29.). Theſe plates are wider than the hole of the piſton, ſo as to reſt on its rim. There are ſimilar plates below the leather of a ſmaller ſize, that they may go into the hollow of the piſton; and the leather is firmly held between the metal plates by ſcrews H, H, which go through all. This is repreſented by the dotted circle IK. Thus the preſſure of the incumbent column of water is ſupported by the plates GG, whoſe circular edges reſt on the brim of the water-way, and thus ſtraight edges reſt on the croſs-bar DD of fig. 26. and 27. This valve is laid on the top of the conical box in ſuch a manner that its middle FF reſts on the croſs-bar. To bind all together, the end of the piſton-rod is formed like a croſs, and the arms MN (fig. 30.) are made to reſt on the diameter FF of the valve, the tail EP going through the hole E in the middle of the leather, and through the mortiſe E of the croſs-bar of the box; as well as through another bar QR (fig. 28. and 29.) which is notched into the lower brim of the box. A key V is then driven into the hole T in the piſton-rod; and this wedges all faſt. The bar QR is made ſtrong; and its extremities project a little, ſo as to ſupport the braſs hoop BB which binds the leather band to the piſton-box."

This piſton has every advantage of ſtrength, tightneſs, and large water-way. The form of the valve (which has given it the name of the *butterfly-valve)* is extremely favourable to the paſſage of the water; and as it has but half the motion of a complete circular valve, leſs water goes back while it is ſhutting.

13. The following piſton is alſo ingenious, and has a good deal of merit. OPPO (pl. XXIV. fig. 5.) is the box of the piſton, having a perforation Q, covered above with a flat valve K, which reſts in a metal plate that forms the top of the box. ABCBA is a ſtirrup of iron to which the box is fixed by ſcrews *a*, *a*, *a*, *a*, whoſe heads are ſunk in the wood. This ſtirrup is perforated at C, to receive the end of the piſton-rod, and a nut H is ſcrewed on below to keep it faſt. DEFED is another ſtirrup, whoſe lower part at DD forms a hoop like the ſole of a ſtirrup, which embraces a ſmall part of the top of the wooden box. The lower end of the piſton-rod is ſcrewed; and before it is put into the holes of the two ſtirrups (through which holes it ſlides freely) a broad nut G is ſcrewed on it. It is then put into the holes, and the nut H firmly ſcrewed up. The packing RR is then wound about the piſton as tight as poſſible till it completely fills the working-barrel of the pump. When long uſe has rendered it in any degree looſe, it may be tightened again by ſcrewing down the nut G. This cauſes the ring DD to compreſs the packing between it and the projecting ſhoulder of the box at PP; and thus cauſes it to ſwell out, and apply itſelf cloſely to the barrel. Prony, in his Architecture Hydraulique, aſcribes this invention to M. Bettancourt.

14. We ſhall add only another form of a perforated piſton; which being on a principle different from all the preceding, will ſuggeſt many others; each of which will have its peculiar advantages. OO in fig. 3. pl. XXIV. repreſents the box of this piſton, fitted to the working-barrel in any of the preceding ways as may be thought beſt. AB is a croſs-bar of four arms, which is fixed to the top of the box. CF is the piſton-rod going

through a hole in the middle of AB, and reaching a little way beyond the bottom of the box. It has a ſhoulder D, which prevents its going too far through. On the lower end there is a thick metal plate, turned conical on its upper ſide, ſo as to fit a conical ſeat PP in the bottom of the piſton-box.

When the piſton-rod is puſhed down, the friction on the barrel prevents the box from immediately yielding. The rod therefore ſlips through the hole of the croſs-bars AB. The plate E, therefore, detaches itſelf from the box. When the ſhoulder D preſſes on the bar AB, the box muſt yield, and be puſhed down the barrels, and the water gets up through the perforation. When the piſton-rod is drawn up again, the box does not move till the plate E lodges in the ſeat PP, and thus ſhuts the water-way; and then the piſton lifts the water which is above it, and acts as the piſton of a ſucking-pump.

This is a very ſimple and effective conſtruction, and makes a very tight valve. It has been much recommended by engineers of the firſt reputation, and is frequently uſed; and, from its ſimplicity, and the great ſolidity of which it is capable, it ſeems very fit for great works. But it is evident that the water-way is limited to leſs than one-half of the area of the working-barrel. For if the perforation of the piſton be one-half of the area, the diameter of the plate or ball EF muſt be greater; and therefore leſs than half the area will be left for the paſſage of the water by its ſides.

15. We come now to conſider briefly the forms which may be given to the valves of an hydraulic engine.

The requiſites of a valve are, that it ſhall be tight, of ſufficient ſtrength to reſiſt the great preſſures to which it is expoſed, that it afford a ſufficient paſſage for the water, and that it do not allow much to go back while it is ſhutting.

The butterfly-valve repreſented in figures 29, &c. is free from moſt of the inconveniences, and ſeems the moſt perfect of the clack valves. Some engineers make their great valves of a pyramidal form, conſiſting of four clacks, whoſe hinges are in the circumference of the water-way, and which meet with their points in the middle, and are ſupported by four ribs which riſe up from the ſides, and unite in the middle. This is an excellent form, affording the moſt ſpacious water-way, and ſhutting very readily. It ſeems to be the beſt poſſible for a piſton. The rod of the piſton is branched out on four ſides, and the branches go through the piſton-box, and are faſtened below with ſcrews. Theſe branches form the ſupport for the four clacks. We have ſeen a valve of this form in a pump of ſix feet diameter, which diſcharged 20 hogſheads of water every ſtroke, and made 12 ſtrokes in a minute, raiſing the water above 22 feet.

16. There is another form of valve, called the *button* or *tail valve*. It conſiſts of a plate of metal AB (fig. 4. pl. XXIV.) turned conical, ſo as exactly to fit the conical cavity *a b* of its box. A tail CD projects from the under ſide, which paſſes through a croſs-bar EF in the bottom of the box, and has a little knob at the end, to hinder the valve from riſing too high.

This valve, when nicely made, is unexceptionable. It has great ſtrength, and is therefore proper for all ſevere ſtrains, and it may be made perfectly tight by grinding. Accordingly it is uſed in all caſes where this is of indiſpenſable conſequence. It is moſt durable, and the only kind that will do for paſſages where ſteam or hot water is to go through. Its only imperfection is a ſmall water-way; which, from what has been ſaid, cannot exceed, nor indeed equal, one-half of the area of the pipe.

If we endeavour to enlarge the water-way, by giving the cone very little taper, the valve frequently ſticks ſo faſt in the ſeat that no force can detach them.—And this ſometimes happens during the working of the machine; and the jolts and blows given to the machine in taking it to pieces, in order to diſcover what has been the reaſon that it has diſcharged no water, frequently detaches the valve, and we find it quite looſe, and cannot tell what has deranged the pump. When this is guarded againſt, and the diminution of the water-way is not of very great conſequence, this is the beſt form of a valve.

17. Analogous to this is the ſimpleſt of all valves. It is nothing more than a ſphere of metal, to which is fitted a ſeat with a ſmall portion of a ſpherical cavity. Nothing can be more effectual than this valve; it always falls into its proper place, and in every poſition fits it exactly. Its only imperfection is the great diminution of the water-way. If the diameter of the ſphere do not conſiderably exceed that of the hole, the touching parts have very little taper, and it is very apt to ſtick faſt. It oppoſes much leſs reſiſtance to the paſſage of the water than the flat under-ſurface of the button-valve. The ſpherical valve muſt not be made too light, otherwiſe it will be hurried up by the water, and much may go back while it is returning to its place.

Belidor deſcribes with great minuteneſs (vol. ii. p. 221, &c.) a valve which unites every requiſite. But it is of ſuch nice and delicate conſtruction, and its defects are ſo great when this exactneſs is not attained, or is impaired by uſe, that we think it hazardous to introduce it into a machine in a ſituation where an intelligent and accurate artiſt is not at hand. For this reaſon we have omitted the deſcription, which cannot be given in few words, nor without many figures; and deſire our curious readers to conſult that author, or peruſe Dr. Deſaguliers's tranſlation of this paſſage. Its principle is preciſely the ſame with the following rude contrivance.

18. Suppoſe ABCD (fig. 2. pl. XXIV.) to be a ſquare wooden trunk. EF is a piece of oak board, exactly fitted to the trunk in an oblique poſition, and ſupported by an iron pin which goes through it at I, one-third of its length from its lower extremity E. The two ends of this board are bevelled, ſo as to apply exactly to the ſides of the trunk. . It is evident, that if a ſtream of water come in the direction BA, its preſſure on the part IF of this board will be greater than that upon EI. It will therefore force it up and ruſh through, making it ſtand almoſt parallel to the ſides of the trunk. To prevent its riſing ſo far, a pin muſt be put in its way. When this current of water changes its direction, the preſſure on the upper ſide of the board being again greateſt on the portion IF, it is forced back again to its former ſituation; and its two extremities reſting on the oppoſite ſides of the trunk, the paſſage is completely ſtopped. This board therefore performs the office of a valve; and this valve is the moſt perfect that can be, becauſe it offers the freeſt paſſage to the water, and it allows very little to get back while it is ſhutting; for the part IE brings up half as much water as IF allows to go down. It may be made extremely tight, by fixing two thin fillets H and G to the ſides of the trunk, and covering thoſe parts of the board with leather which apply to them; and in this ſtate it perfectly reſembles Belidor's fine valve.

19. This conſtruction of the valve ſuggeſts, by the way, a form of an occaſional pump, which may be quickly ſet up by any common carpenter, and will be very effectual in ſmall heights. Let *a b c d e* (fig. 2.) be a ſquare box made to ſlide along this wooden trunk without ſhake, having two of its ſides projecting upwards, terminating like the gable ends of a houſe. A piece of wood *e* is mortiſed into theſe two ſides, and to this the piſton-rod is fixed. This box being furniſhed with a valve ſimilar to the one below, will perform the office of a piſton. If this pump be immerſed ſo deep in the water that the piſton ſhall alſo be under water, we ſcruple not to ſay that its performance will be equal to any. The piſton may be made abundantly tight, by covering its outſide neatly with ſoft leather. And as no pipe can be bored with greater accuracy than a very ordinary workman can make a ſquare trunk, we think this pump will not be very deficient even for a conſiderable ſuction.

Thus much will, we hope, ſuffice for the deſcriptive part of theſe uſeful machines: as to the theory of the *motion* of water in pumps, at the ſame time that it is extremely intricate, it preſents but few reſults that are of any practical utility. The curious ſtudent may be referred to the *Maſchinenlehre* of Langſdorf, the *Hydrodynamique* of Boſſut, the *Hydraulique* of Buat, the *Architecture Hydraulique* of Prony, and the article *Pump* in the Encyclopædia Britannica. The laſt two pieces have furniſhed us with the moſt valuable parts of the preſent article. Some remarks on the variable motion of the piſton-rod may be ſeen under the title PARALLEL *motion* in this volume.

PYROMETER, a machine contrived to meaſure the expanſion of metals, and other bodies, occaſioned by heat.

Muſchenbroeck was the original inventor of the Pyrometer: the nature and conſtruction of his inſtrument may be underſtood from the following account. If we ſuppoſe a ſmall bar of metal, 12 or 15 inches in length, made faſt at one of its extremities, it is obvious that if it be dilated by heat it will become lengthened, and its other extremity will be puſhed forwards. If this extremity then be fixed to the end of a lever, the other end of which is furniſhed with a pinion adapted to a wheel, and if this wheel move a ſecond pinion, the latter a third, and ſo on, it will be evident that by multiplying wheels and pinions in this manner, the laſt will have a very ſenſible motion; ſo that the moveable extremity of the ſmall bar cannot paſs over the hundredth or thouſandth part of a line, without a point of the circumference of the laſt wheel paſſing over ſeveral inches. If this circumference then have teeth fitted into a pinion, to which an index is attached, this index will make ſeveral revolutions, when the dilatation of the bar amounts only to a quantity altogether inſenſible. The portions of this revolution may be meaſured on a dial-plate, divided into equal parts; and by means of the ratio which the wheels bear to the pinions, the abſolute quantity which a certain degree of heat may have expanded the ſmall bar can be aſcertained: or, converſely, by the dilatation of the ſmall bar the degree of heat which has been applied to it may be determined.

Such is the conſtruction of Muſchenbroeck's pyrometer. It is neceſſary to obſerve that a ſmall cup is adapted to the machine, in order to receive the liquid or fuſed matters, ſubjected to experiment, and in which the bar to be tried is immerſed.

When it is required to meaſure, by this inſtrument, a conſiderable degree of heat, ſuch as that of boiling oil or fuſed metal, fill the cup with the matter to be tried, and immerſe the bar of iron into it. The dilatation of the bar, indicated by the index, will point out the degree of heat it has aſſumed, and which muſt neceſſarily be equal to that of the matter into which it is immerſed.

This machine evidently ſerves to determine the ratio of the dilatation of metals, &c.: for by ſubſtituting in the room of the pyrometric bar other metallic bars of the ſame length, and then expoſing them to an equal degree of heat, the ratios of their dilatation will be ſhewn by the motion of the index.

Muſchenbroeck has given a table of the expanſion of the different metals, in the ſame degree of heat. Having prepared cylindric rods of iron, ſteel, copper, braſs, tin, and lead, he expoſed them firſt to a *pyrometer* with one flame in the middle; then with two flames; and ſucceſſively to one with three, four, and five flames. But previous to this trial, he took care to cool them equally, by expoſing them ſome time upon the ſame ſtone, when it began to freeze, and Fahrenheit's thermometer was at thirty-two degrees. The effects of theſe experiments are digeſted in the following table, where the degrees of expanſion are marked in parts equal to the $\frac{1}{12500}$ part of an inch.

Expanſion of	Iron	Steel	Copper	Braſs	Tin	Lead
By one flame	80	85	89	110	153	155
By two flames placed cloſe together	117	123	115	220		274
By two flames 2½ inches diſtant	109	94	92	141	219	263
By three flames placed cloſe together	142	168	193	275		
By four flames placed cloſe together	211	270	270	361		
By five flames	230	310	310	377		

It is to be obſerved of tin, that it will eaſily melt, when heated by two flames placed together. Lead commonly melts with three flames, placed together, eſpecially if they burn long.

From theſe experiments, ſo far as they are correct, it appears, at firſt view, that iron is the leaſt rarefied of any of theſe metals, whether it be heated by one or more flames; and therefore is moſt proper for making machines or inſtruments which we would have free from any alterations by heat or cold, as the rods of pendulums, for clocks, &c. So likewiſe the meaſures of yards or feet ſhould, if of metal, be made of iron, that their length may be as nearly as poſſible the ſame, ſummer and winter. The expanſion of lead and tin, by only one flame, is nearly the ſame; that is, almoſt double of the expanſion of iron. It is likewiſe obſervable, that the flames placed together cauſe a greater rarefaction than when they have a ſenſible interval between them; iron, in the former caſe, being expanded 117 degrees, and only 109 in the latter; the reaſon of which difference is obvious. By comparing the expanſions of the ſame metal, produced by one, two, three, or more flames, it appears, that two flames do not cauſe double the expanſion of one; nor three flames three times that expanſion, but always leſs; and theſe expanſions differ ſo much the more from the ratio of the number of flames, as there are more flames acting at the ſame time. It is alſo obſervable, that metals are not expanded equally, at the time of their melting, but ſome more, ſome leſs. Thus tin began to run, when rarefied 219 degrees; whereas braſs was expanded 377 degrees, and yet was far from melting.

By the help of this inſtrument Mr. Ellicott found, upon a medium, that the expanſions of bars of different metals, as nearly of the ſame dimenſions as poſſible, by the ſame degree of heat, were as follow;

Gold,	Silver,	Braſs,	Copper,	Iron,	Steel,	Lead,
73	103	95	89	60	56	149

The great difference between the expanſions of iron and braſs has been applied with good ſucceſs to remedy the irregularities in pendulums ariſing from heat. Phil. Tranſ. vol. xlvii. p. 485. See PENDULUM.

Mr. Graham uſed to meaſure the minute alterations, in length, of metal bars, by advancing the point of a micrometer-ſcrew, till it ſenſibly ſtopped againſt the end of the bar to be meaſured. This ſcrew, being ſmall and very lightly hung, was capable of agreement within the three or four-thouſandth part of an inch. On this general principle Mr. Smeaton contrived his pyrometer, in which the meaſures are determined by the contact of a piece of metal with the point of a micrometer-ſcrew.

The following table ſhews how much a foot in length of each metal grows longer by an increaſe of heat, correſponding to 180° of Fahrenheit's thermometer, or to the difference between freezing and boiling water, expreſſed in ſuch parts of which the unit is equal to the 10,000 part of an inch.

1. White glaſs barometer tube,	100
2. Martial regulus of antimony,	130
3. Bliſtered ſteel,	138
4. Hard ſteel,	147

5. Iron,	151
6. Biſmuth,	167
7. Coppered hammered	204
8. Copper eight parts, with tin one,	218
9. Caſt braſs,	225
10. Braſs ſixteen parts, with tin one,	229
11. Braſs wire,	232
12. Speculum metal,	232
13. Spelter ſolder, viz. braſs two parts, zinc one,	247
14. Fine pewter,	274
15. Grain tin,	298
16. Soft ſolder, viz. lead two, tin one,	301
17. Zinc eight parts, with tin one, a little hammered,	323
18. Lead,	344
19. Zinc or ſpelter,	353
20. Zinc hammered half an inch per foot,	373

M. de Luc, in conſequence of a hint ſuggeſted to him by the late Mr. Ramſden, invented a pyrometer, the baſis of which is a rectangular piece of deal board two feet and a half long, 15 inches broad, and one inch and a half thick; and to this all the other parts are fixed. This is mounted in the manner of a table, with four deal legs, each a foot long and an inch and a half ſquare, well fitted near its four angles, and kept together at the other ends by four firm croſs pieces. This ſmall table is ſuſpended by a hook to a ſtand; the board being in a vertical ſituation in the direction of its grain, and bearing its legs forward in ſuch a manner as that the croſs-pieces which join them may form a frame, placed vertically facing the obſerver. This frame ſuſtains a microſcope, which is firmly fixed in another frame that moves in the former by means of grooves, but with a very conſiderable degree of tightneſs; the friction of which may be increaſed by the preſſure of four ſcrews. The inner ſliding frame, which is likewiſe of deal, keeps the tube of the microſcope in a horizontal poſition, and in great part without the frame, inſomuch that the end which carries the lens is but little within the ſpace between the frame and the board. This microſcope is conſtructed in ſuch a manner as that the object obſerved may be an inch diſtant from the lens; and it has a wire which is ſituated in the focus of the glaſſes, in which the objects appeared reverſed. At the top of the apparatus there is a piece of deal, an inch and a half thick and two inches broad, laid in a horizonal direction from the board to the top of the frame. To this piece the rods of the different ſubſtances, whoſe expanſion by heat is to be meaſured, are ſuſpended: one end of it ſlides into a ſocket, which is cut in the thickneſs of the board; and the other end, which reſts upon the frame, meets there with a ſcrew which makes the piece move backward and forward, to bring the objects to the focus of the microſcope. There is a cork very ſtrongly driven through a hole bored vertically through this piece; and in another vertical hole made through the cork, the rods are fixed at the top; ſo that they hang only, and their dilatation is not counteracted by any preſſure. In order to heat the rods, a cylindrical bottle of thin glaſs, about 21 inches high, and four inches in diameter, is placed in the inſide of the machine, upon a ſtand independent of the reſt of the apparatus. In this bottle the rods are ſuſpended at a little leſs than an inch diſtance from one of the inſides, in order to have them near the microſcope. Into it is poured water of different degrees of heat, which muſt be ſtirred about, by moving upwards and downwards, at one of the ſides of the bottle, a little piece of wood, faſtened horizontally at the end of a ſtick: in this water is hung a thermometer, the ball of which reaches to the middle of the height of the rods. During theſe operations the water riſes to the cork, which thus determines the length of the heated part; the bottle is covered, to prevent the water from cooling too rapidly at the ſurface; and a thin caſe of braſs prevents the vapour from fixing upon the piece of deal to which the rods are fixed.

The late Mr. Ferguſon alſo invented two pyrometers, deſcriptions and figures of which are given in his Lectures.

Mr. Wedgwood, the ingenious manufacturer of the fineſt earthenware from baſaltic maſſes, or *terra cotta*, has contrived a curious pyrometer: he employs ſmall cubes of dry clay; becauſe that ſpecies of earth has the remarkable property of *contracting* in its bulk, when ſubmitted to the fire, and not again expanding on ſuddenly expoſing it to the cold air. In order to aſcertain the preciſe degree of heat in an oven, he puts one of his clay-cubes into it; and, after having acquired the temperature of the place, he immediately plunges it into cold water. Now, the ſize of the cube (that was exactly adjuſted to half an inch ſquare) is meaſured between two braſs rules, the ſides of which are ſomewhat obliquely diſpoſed, ſo as to form an inclining groove, into which the cube may be ſlidden. In proportion as the bulk of the latter has been contracted by heat, it paſſes down deeper between the ſcales, on which the various degrees of temperature have been previouſly marked. Thus, when the diviſion of the ſcale commences from the point of red heat viſible in day-light, and the whole range be divided into 240 equal parts, it will be found that Swediſh copper melts at 28; gold at 32; iron at from 130 to 150 degrees: above this point, the cubes could not be heated. But if one of theſe clay ſquares be put into an oven where other materials, ſuch as bread, earthen-ware, &c. are to be baked, they may be uſefully employed, for regulating the neceſſary degree of heat.

M. Fourmy has lately given, in the *Journal des Mines*, a paper "On the Thermometers of baked Earths, termed Pyrometers;" in which he ſhews that the effect of ſhrinking, upon which Wedgwood's pyrometer is founded, does not reſult ſolely and invariably from the cauſe to which it is aſcribed; that it is not neceſſarily proportionate to it; that, whatever may be the graduation and the continuity of temperature applied to an aluminous mixt, its ſhrinking is not only not neceſſarily graduated, or neceſſarily continuous, but it alſo does not always neceſſarily take place; and therefore that a pyrometer founded upon ſuch ſhrinking does not afford ſo conſtant and accurate a meaſure for the higheſt degrees of heat, as the dilatation of mercury or of alcohol does for the lower. A tranſlation of M. Fourmy's obſervations is inſerted in the *Repertory of Arts*, &c. No. 38. N. S.

RAMSDEN's MACHINE *for dividing* MATHEMATICAL INSTRUMENTS is an uſeful invention, by which theſe diviſions can be performed with exceedingly great accuracy, ſuch as would formerly have been deemed incredible. On diſcovering the method of conſtructing this machine, its inventor, Mr. Jeſſe Ramſden, received 615*l.* from the commiſſioners of longitude; engaging himſelf to inſtruct a certain number of perſons, not exceeding ten, in the method of making and uſing this machine from the 28th October 1775, to 28th October 1777: alſo binding himſelf to divide all octants and ſextants by the ſame engine, at the rate of three ſhillings for each octant, and ſix ſhillings for each braſs ſextant, with Nonius's diviſions to half-minutes, for as long time as the commiſſioners ſhould think proper to let the engine remain in his poſſeſſion. Of this ſum of 615*l.* paid to Mr. Ramſden, 300*l.* were given him as a reward for the improvement made by him in diſcovering the engine, and the remaining 315*l.* for his giving up the property of it to the commiſſioners. The following deſcription of the engine is that given upon oath by Mr. Ramſden himſelf.

"This engine conſiſts of a large wheel of bell-metal, ſupported on a mahogany ſtand, having three legs, which are ſtrongly connected together by braces, ſo as to make it perfectly ſteady. On each leg of the ſtand is placed a conical friction-pulley, whereon the dividing wheel reſts: to prevent the wheel from ſliding off the friction-pulleys, the bell-metal centre under it turns in a ſocket on the top of the ſtand.

"The circumference of the wheel is ratched or cut (by a method which will be deſcribed hereafter) into 2160 teeth, in which an endleſs ſcrew acts. Six revolutions of the ſcrew will move the wheel a ſpace equal to one degree.

"Now a circle of braſs being fixed on the ſcrew arbor, having its circumference divided into 60 parts, each diviſion will conſequently anſwer to a motion of the wheel of 10 ſeconds, ſix of them will be equal to a minute, &c.

"Several different arbors of tempered ſteel are truly ground into the ſocket in the centre of the wheel. The upper parts of the arbors that ſtand upon the plane are turned of various ſizes, to ſuit the centres of different pieces of work to be divided.

"When any inſtrument is to be divided, the centre of it is very exactly fitted on one of theſe arbors; and the inſtrument is fixed down to the plane of the dividing wheel, by means of ſcrews, which fit into holes made in the radii of the wheel for that purpoſe.

"The inſtrument being thus fitted on the plane of the wheel, the frame which carries the dividing point is connected at one end by finger ſcrews with the frame which carries the endleſs ſcrew; while the other end embraces that part of the ſteel arbor which ſtands above the inſtrument to be divided, by an angular notch in a piece of hardened ſteel: by this means both ends of the frame are kept perfectly ſteady, and free from any ſhake.

"The frame carrying the dividing-point or tracer is made to ſlide on the frame which carries the endleſs ſcrew to any diſtance from the centre of the wheel as the radius of the inſtrument to be divided may require, and may be there faſtened by tightening two clumps; and the dividing-point or tracer being connected with the clumps by the double-jointed frame, admits a free and eaſy motion towards or from the centre for cutting the diviſions, without any lateral ſhake.

"From what has been ſaid, it appears that an inſtrument thus fitted on the dividing-wheel may be moved to any angle by the ſcrew and divided circle on its arbor, and that this angle may be marked on the limb of the inſtrument with the greateſt exactneſs by the dividing-point or tracer, which can only move in a direct line tending to the centre, and is altogether freed from thoſe inconveniences that attend cutting by means of a ſtraight edge. This method of drawing lines will alſo prevent any error that might ariſe from an expanſion or contraction of the metal during the time of dividing.

"The ſcrew frame is fixed on the top of a conical pillar, which turns freely round its axis, and alſo moves freely towards or from the centre of the wheel, ſo that the ſcrew-frame may be entirely guided by the frame which connects it with the centre; by this means any eccentricity of the wheel and the arbor would not produce any error in the dividing; and by a particular contrivance (which will be deſcribed hereafter), the ſcrew when preſſed againſt the teeth of the wheel always moves parallel to itſelf; ſo that a line joining the centre of the arbor and the tracer continued will always make equal angles with the ſcrew.

" Fig. 1. in Pl. XXVI. repreſents a perſpective view of the engine.

" Fig. 2. in Pl. XXVII. is a plan of which fig. 3. repreſents a ſection on the line Π Δ.

" The large wheel A is 45 inches in diameter, and has ten radii, each being ſupported by edge-bars, as repreſented in fig. 3. Theſe bars and radii are connected by the circular ring B, 24 inches in diameter and 3 deep; and, for greater ſtrength, the whole is caſt in one piece in bell-metal.

" As the whole weight of the wheel A reſts on its ring B, the edge bars are deepeſt where they join it; and from thence their depth diminiſhes, both towards the centre and circumference, as repreſented in fig. 3.

" The ſurface of the wheel A was worked very even and flat, and its circumference turned true. The ring C, of fine braſs, was fitted very exactly on the circumference of the wheel; and was faſtened thereon with ſcrews, which, after being ſcrewed as tight as poſſible, were well rivetted. The face of a large chuck being turned very true and flat in the lathe, the flattened ſurface A (fig. 3.) of the wheel was faſtened againſt it with hold-faſts; and the two ſurfaces and circumference of the ring C, a hole through the centre and the plane part round [b] it, and the lower edge of the ring B, were turned at the ſame time.

" D is a piece of hard bell-metal, having the hole, which receives the ſteel arbor [d], made very ſtraight and true. This bell-metal was turned very true on an arbor; and the face, which reſts on a wheel at [b], was turned very flat, ſo that the ſteel arbor [d] might ſtand perpendicular to the plane of the wheel: this bell-metal was faſtened to the wheel by ſix ſteel ſcrews [l].

" A braſs ſocket Z is faſtened on the centre of the mahogany ſtand, and receives the lower part of the bell-metal piece D, being made to touch the bell-metal in a narrow part near the mouth, to prevent any obliquity of the wheel from bending the arbor: good fitting is by no means neceſſary here; ſince any ſhake in this ſocket will produce no bad effect, as will appear hereafter when we deſcribe the cutting-frame.

" The wheel was then put on its ſtand, the lower edge of the ring B (fig 1, 2, and 3.) reſting on the circumference of three conical friction-pulleys W, to facilitate its motion round its centre. The axis of one of theſe pulleys is in a line joining the centre of the wheel and the middle of the endleſs ſcrew, and the other two placed ſo as to be at equal diſtances from each other.

" (Fig. 1.) is a block of wood ſtrongly faſtened to one of the legs of the ſtand; the piece [g] is ſcrewed to the upper ſide of the block, and has half-holes, in which the tranſverſe axis [h] (fig. 4.) turns: the half-holes are kept together by the ſcrews [i].

" The lower extremity of the conical pillar P (fig. 1. & 4.) terminates in a cylindrical ſteel pin [k], (fig. 4.) which paſſes through and turns in the tranſverſe axis [h], and is confined by a cheek and ſcrew.

" To the upper end of the conical pillar is faſtened the frame G, (fig. 4.) in which the endleſs ſcrew turns: the pivots of the ſcrew are formed in the manner of two fruſtums of cones joined by a cylinder, as repreſented at X (fig. 5). Theſe pivots are confined between half-poles, which preſs only on the conical parts, and do not touch the cylindric parts: the half-holes are kept together by ſcrews [a] which may be tightened at any time, to prevent the ſcrew from ſhaking in the frame.

" On the ſcrew-arbor is a ſmall wheel of braſs K (fig. 1, 2, 4, 5.), having its outſide edge divided into 60 parts, and numbered at every 6th diviſion with 1, 2, &c. to 10. The motion of this wheel is ſhown by the index [y] (fig. 4 & 5.) on the ſcrew-frame G.

" H (fig. 1.) repreſents a part of the ſtand, having a parallel ſlit in the direction towards the centre of the wheel, large enough to receive the upper part of the conical braſs pillar P, which carries the ſcrew and its frame: and as the reſiſtance, when the wheel is moved by the endleſs-ſcrew, is againſt the ſide of the ſlit H which is towards the left hand, that ſide of the ſlit is faced with braſs, and the pillar is preſſed againſt it by a ſteel ſpring on the oppoſite ſide: by this means the pillar is ſtrongly ſupported laterally, and yet the ſcrew may be eaſily preſſed from or againſt the circumference of the wheel, and the pillar will turn freely on its axis to take any direction given it by the frame L.

" At each corner of the piece I (fig. 4.) are ſcrews [n] of tempered ſteel, having poliſhed conical points: two of them turn in conical holes in the ſcrew-frame near [o], and the points of the other two ſcrews turn in the holes in the piece Q; the ſcrews [p] are of ſteel, which being tightened, prevent the conical pointed ſcrews from unturning when the frame is moved.

"L (fig. 1, 2, 6.) is a braſs frame, which ſerves to connect the endleſs-ſcrew, its frame, &c. with the centre of the wheel: each arm of this frame is terminated by a ſteel ſcrew, that may be paſſed through any of the holes [q] in the piece Q (fig. 4.), as the thickneſs of work to be divided on the wheel may require, and are faſtened by the finger-nuts [r] (fig. 1. & 2.)

"At the other end of this frame is a flat piece of tempered ſteel [b] (fig. 6.), wherein is an angular notch: when the endleſs-ſcrew is preſſed againſt the teeth of the circumference of the wheel, which may be done by turning the finger-ſcrew S (fig. 1 & 2.) to preſs againſt the ſpring [t], this notch embraces and preſſes againſt the ſteel arbor [d]. This end of the frame may be raiſed or depreſſed by moving the priſmatic ſlide [u] (fig. 2.), which may be fixed at any height by the four ſteel-ſcrews [v] (fig. 1, 2, 6.).

"The bottom of this ſlide has a notch [k] (fig. 1. & 6.), whoſe plane is parallel to the endleſs-ſcrew; and by the point of the arbor [d] (fig. 3.) reſting in this notch, this end of the frame is prevented from tilting. The ſcrew S (fig. 1, 2.) is prevented from unturning, by tightening the finger-nut [w].

"The teeth on the circumference of the wheel were cut by the following method:

"Having conſidered what number of teeth on the circumference would be moſt convenient, which in this engine is 2160, or 360 multiplied by 6, I made two ſcrews of the ſame dimenſions, of tempered ſteel, in the manner hereafter deſcribed, the interval between the threads being ſuch as I knew by calculation would come within the limits of what might be turned off the circumference of the wheel: one of theſe ſcrews, which was intended for ratching or cutting the teeth, was notched acroſs the threads, ſo that the ſcrew, when preſſed againſt the edge of the wheel and turned round, cut in the manner of a ſaw. Then having a ſegment of a circle a little greater than 60 degrees, of about the ſame radius with the wheel, and the circumference made true, from a very fine centre, I deſcribed an arch near the edge, and ſet off the cord of 60 degrees on this arch. This ſegment was put in the place of the wheel, the edge of it was ratched, and the number of revolutions and parts of the ſcrew contained between the interval of the 60 degrees were counted. The radius was corrected in the proportion of 360 revolutions, which ought to have been in 60 degrees, to the number actually found; and the radius, ſo corrected, was taken in a pair of beam-compaſſes: while the wheel was on the lath, one foot of the compaſſes was put in the centre, and with the other a circle was deſcribed on the ring; then half the depth of the threads of the ſcrew being taken in dividers, was ſet ſrom this circle outwards, and another circle was deſcribed cutting this point; a hollow was then turned on the edge of the wheel of the ſame curvature as that of the ſcrew at the bottom of the threads: the bottom of this hollow was turned to the ſame radius or diſtance from the centre of the wheel, as the outward of the two circles before mentioned.

"The wheel was now taken off the lathe; and the bell-metal piece D (fig. 3.) was ſcrewed on as before directed, which after this ought not to be removed.

"From a very exact centre a circle was deſcribed on the ring C (fig. 1, 2, 3.), about $\frac{4}{10}$ of an inch within where the bottom of the teeth would come. This circle was divided with the greateſt exactneſs I was capable of, firſt into five parts, and each of theſe into three. Theſe parts were then biſected four times: (that is to ſay), ſuppoſing the whole circumference of the wheel to contain 2160 teeth, this being divided into five parts, each would contain 432 teeth; which being divided into three parts, each of them would contain 144; and this ſpace biſected four times would give 72, 36, 18, and 9: therefore each of the laſt diviſions would contain nine teeth. But, as I was apprehenſive ſome error might ariſe from quinqueſection and triſection, in order to examine the accuracy of the diviſions, I deſcribed another circle on the ring C (fig. 7.) $\frac{1}{10}$ inch within the former, and divided it by continual biſections, as 2160, 1080, 540, 270, 135, 67$\frac{1}{2}$, and 33$\frac{3}{4}$; and as the fixed wire (to be deſcribed preſently) croſſed both the circles, I could examine their agreement at every 135 revolutions; (after ratching, could examine it at every 33$\frac{3}{4}$): but, not finding any ſenſible difference between the two ſets of diviſions, I, for ratching, made choice of the former; and, as the coincidence of the fixed wire with an interſection could be more exactly determined than with a dot or diviſion, I therefore made uſe of interſections in both circles before deſcribed.

"The arms of the frame L (fig. 7.) were connected by a thin piece of braſs of $\frac{3}{4}$ of an inch broad, having a hole in the middle of $\frac{4}{10}$ of an inch in diameter; acroſs this hole a ſilver wire was fixed exactly in a line to the centre of the wheel: the coincidence of this wire with the interſections was examined by a lens $\frac{7}{10}$ inch focus, fixed in a tube which was attached to one of the arms L*. Now a handle or winch being fixed on the end of the ſcrew, the diviſion marked 10 on the circle K was ſet to its index, and, by means of a clamp and adjuſting-ſcrew for that purpoſe, the interſection marked 1 on the circle

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* The interſections are marked for the ſake of illuſtration, though properly inviſible, they lying under the braſs plate.

C was ſet exactly to coincide with the fixed wire; the ſcrew was then carefully preſſed againſt the circumference of the wheel, by turning the finger-ſcrew S; then, removing the clamp, I turned the ſcrew by its handle 9 revolutions, till the interſection marked 240 came nearly to the wire; then, unturning the finger-ſcrew S, I releaſed the ſcrew from the wheel, and turned the wheel back till the interſection marked 2 exactly coincided with the wire; and, by means of the clamp before mentioned, the diviſion 10 on the circle being ſet to its index, the ſcrew was preſſed againſt the edge of the wheel by the finger-ſcrew S; the clamps were removed, and the ſcrew turned nine revolutions till the interſection marked 1 nearly coincided with the fixed wire; the ſcrew was releaſed from the wheel by unturning the finger-ſcrew S as before; the wheel was turned back till the interſection 3 coincided with the fixed wire; the diviſion 10 on the circle being ſet to its index, the ſcrew was preſſed againſt the wheel as before, and the ſcrew was turned 9 revolutions, till the interſection 2 nearly coincided with the fixed wire, and the ſcrew was releaſed; and I proceeded in this manner till the teeth were marked round the whole circumference of the wheel. This was repeated three times round, to make the impreſſion of the ſcrew deeper. I then ratched the wheel round continually in the ſame direction without ever diſengaging the ſcrew; and, in ratching the wheel about 300 times round, the teeth were finiſhed.

“ Now it is evident, if the circumference of the wheel was even one tooth or ten minutes greater than the ſcrew would require, this error would in the firſt inſtance be reduced to $\frac{1}{240}$ part of a revolution, or two ſeconds and a half; and theſe errors or inequalities of the teeth were equally diſtributed round the wheel at the diſtance of nine teeth from each other. Now, as the ſcrew in ratching had continually hold of ſeveral teeth at the ſame time, and theſe conſtantly changing, the above-mentioned inequalities ſoon corrected themſelves, and the teeth were reduced to a perfect equality. The piece of braſs which carries the wire was now taken away, and the cutting-ſcrew was alſo removed, and a plain one (hereafter deſcribed) put in its place: on one end of the ſcrew is a ſmall braſs circle, having its edge divided into 60 equal parts, and numbered at every ſixth diviſion, as before mentioned. On the other end of the ſcrew is a ratchet-wheel C, having 60 teeth, covered by the hollowed circle [d] (fig. 5.), which carries two clicks that catch upon the oppoſite ſides of the ratchet when the ſcrew is to be moved forwards. The cylinder S turns on a ſtrong ſteel arbor F, which paſſes through and is firmly ſcrewed to the piece Y: this piece, for greater firmneſs, is attached to the ſcrew-frame G (fig. 4.) by the braces [v]: a ſpiral groove or thread is cut on the outſide of the cylinder S, which ſerves both for holding the ſtring, and alſo giving motion to the lever J on its centre by means of a ſteel tooth [n], that works between the threads of the ſpiral. To the lever is attached a ſtrong ſteel pin [m], on which a braſs ſocket [r] turns: this ſocket paſſes through a ſlit in the piece [p], and may be tightened in any part of the ſlit by the finger-nut [f]: this piece ſerves to regulate the number of revolutions of the ſcrew for each tread of the treadle R.

"T (fig. 1.) is a braſs box containing a ſpiral ſpring; a ſtrong gut is faſtened and turned three or four times round the circumference of this box; the gut then paſſes ſeveral times round the cylinder S, and from thence down to the treadle R (fig. 1.). Now, when the treadle is preſſed down, the ſtring pulls the cylinder S round its axis, and the clicks catching hold of the teeth on the ratchet carry the ſcrew round with it, till, by the tooth [n] working in the ſpiral groove, the lever J (fig. 4.) is brought near the wheel [d], and the cylinder ſtopped by the ſcrew-head [x] ſtriking on the top of the lever J; at the ſame time the ſpring is wound up by the other end of the gut paſſing round the box T (fig. 1.). Now, when the foot is taken off the treadle, the ſpring unbending itſelf pulls back the cylinder, the clicks leaving the ratchet and ſcrew at reſt till the piece [t] ſtrikes on the end of the piece [p] (fig. 1.): the number of revolutions of the ſcrew at each tread is limited by the number of revolutions the cylinder is allowed to turn back before the ſtop ſtrikes on the piece [p].

"When the endleſs-ſcrew was moved round its axis with a conſiderable velocity, it would continue that motion a little after the cylinder S (fig. 1. and 4.) was ſtopped: to prevent this, the angular lever η was made; that when the lever J comes near to ſtop the ſcrew [x], it, by a ſmall chamfer, preſſes down the piece κ of the angular lever; this brings the other end η of the ſame lever forwards, and ſtops the endleſs-ſcrew by the ſteel pin μ ſtriking upon the top of it: the foot of the lever is raiſed again by a ſmall ſpring preſſing on the brace [v].

"D, two clamps, connected by the piece α, ſlide one on each arm of the frame L (fig. 1, 2, 6.), and may be fixed at pleaſure by the four finger-ſcrews s, which preſs againſt ſteel ſprings to avoid ſpoiling the arms: the piece [q] is made to turn without ſhake between two conical pointed ſcrews [f], which are prevented from unturning by tightening the finger-nuts N.

"The piece M (fig. 6.) is made to turn on the piece [q], by the conical pointed ſcrews [f] reſting in the hollow centres [e].

"As there is frequent occaſion to cut diviſions on inclined planes, for that purpoſe the piece γ, in which the tracer is fixed, has a conical axis at each end, which turn in half holes: when the tracer is ſet to any inclination, it may be fixed there by tightening the ſteel ſcrews β.

" *Deſcription of the Engine by which the Endleſs-ſcrew of the Dividing-engine was cut.*

" Fig. 9. repreſents this engine of its full dimenſions ſeen from one ſide.

" Fig. 8. the upper ſide of the ſame as ſeen from above.

" A repreſents a triangular bar of ſteel, to which the triangular holes in the pieces B and C are accurately fitted, and may be fixed on any part of the bar by the ſcrews D.

" E is a piece of ſteel whereon the ſcrew is intended to be cut; which, after being hardened and tempered, has its pivots turned in the form of two fruſtums of cones, as repreſented in the drawings of the dividing-engine (fig. 5.). Theſe pivots were exactly fitted to the half-holes F and T, which were kept together by the ſcrews Z.

" H repreſents a ſcrew of untempered ſteel, having a pivot I, which turns in the hole K. At the other end of the ſcrew is a hollow centre, which receives the hardened conical point of the ſteel pin M. When this point is ſufficiently preſſed againſt the ſcrew, to prevent its ſhaking, the ſteel pin may be fixed by tightening the ſcrews Y.

" N is a cylindric nut, moveable on the ſcrew H; which, to prevent any ſhake, may be tightened by the ſcrews O. This nut is connected with the ſaddle-piece P by means of the intermediate univerſal joint W, through which the arbor of the ſcrew H paſſes. A front view of this piece, with a ſection acroſs the ſcrew-arbor, is repreſented at X. This joint is connected with the nut by means of two ſteel ſlips S, which turn on pins between the cheeks T on the nut N. The other ends of theſe ſlips S turn in like manner on pins (a). One axis of this joint turns in a hole in the cock (b), which is fixed to the ſaddle-piece; and the other turns in a hole (d), made for that purpoſe in the ſame piece on which the cock (b) is fixed. By this means, when the ſcrew is turned round, the ſaddle-piece will ſlide uniformly along the triangular bar A.

" K is a ſmall triangular bar of well-tempered ſteel, which ſlides in a groove of the ſame form on the ſaddle-piece P. The point of this bar or cutter is formed to the ſhape of the thread intended to be cut on the endleſs-ſcrew. When the cutter is ſet to take proper hold of the intended ſcrew, it may be fixed by tightening the ſcrews (e), which preſs the two pieces of braſs G upon it.

"Having meaſured the circumference of the dividing-wheel, I found it would require a ſcrew about one thread in a hundred coarſer than the guide-ſcrew H. The wheels on the guide-ſcrew arbor H, and that on the ſteel E, on which the ſcrew was to be cut, were proportioned to each other to produce that effect, by giving the wheel L 198 teeth, and the wheel Q 200. Theſe wheels communicated with each other by means of the intermediate wheel R, which alſo ſerved to give the threads on the two ſcrews the ſame direction.

"The ſaddle-piece P is confined on the bar A by means of the pieces (g), and may be made to ſlide with a proper degree of tightneſs by the ſcrews (n)."

REVERSING OF MOTIONS, *contrivances for.* We do not here mean to ſpeak of alternating or reciprocating motions after intervals of ſhort continuance; thoſe being already treated of in the introductory part of this volume, alſo under the title PARALLEL *motions*, beſides that they occur incidentally in the ſeparate deſcriptions of ſeveral machines. We ſhall now mention ſome methods of reverſing motions after much longer intervals; as in the caſe of drawing up buckets from wells or mines, where no change of direction may be required for ſeveral minutes; or in different kinds of mill-work, where the direction may not be changed for ſome hours.

Contrivances to effect ſuch reverſion of motion are very numerous; but almoſt all of them may be reduced to two general methods: for the required change is generally produced either by making two equal pinions on one and the ſame axis take alternately into the teeth of thoſe parts of a larger wheel which are nearly diametrically oppoſite; or, by means of an additional wheel which may, as the practical mechanics term it, be thrown in and out of gear alternately.

In many engines for drawing buckets out of mines that are moved by horſes, the motion is frequently reverſed by turning round the animal, and cauſing him to retrace his ſteps and draw the contrary way: but this is found very injurious to the horſe, a circumſtance which has frequently led to the adoption of other methods. In Emerſon's Mechanics a ſimple contrivance is deſcribed, conſiſting merely of a horizontal face-wheel upon the ſame vertical ſhaft as the horſepole is attached to, and two equal pinions upon the ſame axle as carries the drum or barrel on which the rope winds. The axle which carries the drum and pinions is fixed horizontally a little above a diameter of the face-wheel; and firſt one and then the other of the pinions is made to be driven by that wheel; thus, manifeſtly, reverſing the motion as required. There are two methods of attaching theſe pinions to the axle, and making them to be acted upon by the face-wheel: in one of them, the pinions are faſtened upon the axle at a diſtance from each other exceeding the diameter of the face-wheel only 3 or 4 inches; then, the axle being moved horizontally through this ſmall diſtance brings firſt one and then the other pinion into contact with the wheel at oppoſite extremities of a diameter, and thus changes the direction of the motion; but this method is attended with the diſadvantage of having often to move a heavy weight with the horizontal axle, beſides that there is much danger of breaking the teeth of the pinions and wheel when they firſt come to embrace each other. In the ſecond method, the lanterns or pinions both turn conſtantly with the face-wheel, but they play freely upon their common axle, except they are ſtopped by a pin which *fixes* them; the application of ſuch pin to firſt the one and then the other of the lanterns produces the alternating motion, as propoſed.

M. Prony has two contrivances for reverſing the motion in horſe-whims, without changing that of the animal: in both of which, however, the general principle is the ſame as that adopted by Mr. Emerſon. In the firſt a horizontal wheel, toothed at its face, lay juſt *above* two vertical pinions, fixed on the oppoſite extremities of an axis of the length of its diameter. This wheel was ſo contrived as to incline a little from its horizontal poſition to either ſide at pleaſure; ſo that on the one inclination its teeth locked with thoſe of one pinion, and receded from the other; and on the other poſition, its operation on the pinions was reverſed: by which the axis of the pinions turned round firſt in one direction, and afterwards in the contrary.

M. Prony, finding this method ſubject to ſome inconveniences, contrived the following, which he eſteems much ſuperior to it. An horizontal wheel, toothed at its face, and attached to a perpendicular arbor (which gives it motion), turns two pinions, moveable on the ſame axis, which it meets at the oppoſite ſides of its circumference: theſe pinions are not attached to the axis, but turn round freely upon it: the intermediate part of the axis is ſquare, and has, adjoining to each pinion, boxes which ſlide back and forwards on it, each of which ſupport a faced wheel, with ſtrong ſerrated teeth; the ſerration being in a different direction on the oppoſite wheels: the boxes are connected by two iron bars, ſo as to change their places by one movement; to the pinions there are alſo ſerrated faced wheels attached, ſo as to lock on thoſe oppoſite to them on the ſliding boxes. From this conſtruction it follows, that when the boxes are ſlidden to one extremity of the axis, the pinion at that ſide will be connected with the axle, and communicate its motion to it in one direction; and when the boxes are moved to the other extremity, then the firſt pinion will be diſengaged, and the ſecond be locked to the axle, and cauſe it to turn round in a direction the reverſe of that in which it moved before. There is a lever on another axle, whoſe office is to move the before-mentioned boxes backwards and forwards: an arm projects from the axis, which moves between two pieces, proceeding from the frame connected with the boxes: the lever riſes upwards, and has a weight at its top, by which it preſſes ſtrongly in either direction, when it paſſes the perpendicular poſition; forming thus the contrivance vulgarly called a tumbling-bob, which is uſed in various engines for a ſimilar purpoſe. Upon the ſame axle on which the pinions move is faſtened a drum-wheel, round which paſſes the chain or cord to which the buckets are attached; another chain or cord is placed below the buckets, from the bottom of one to that of the other, to form an equilibrium between the whole of the appendage of one bucket and that of the other in all poſitions. A bar is ſo placed, that, on one of the buckets riſing to a certain height, it catches the bar, forces it upwards, and thereby throws over the tumbling-bob connected with its other extremity: this reverſes the movement of the buckets; and, on the other bucket riſing, it operates in the ſame way on another lever, which throws the bob to the other ſide, and cauſes the firſt bucket to riſe again.

M. Prony has annexed a contrivance to this engine by which the horſe that puts it in motion is diſengaged when any accident happens, which would tend to ſtop the movement of the wheels: for this purpoſe the traces paſs under two pulleys in the ends of the yoke; and their extremities, which have loops wrought in them, are thereby attached to two pins in a roller, round which a cord is wound two or three turns, and paſſes from thence through rings in the lever, which cauſes the arbor to revolve, and over a pulley on the arbor to a weight which hangs beſide it. When the draught exceeds this weight, it is evident the roller will be drawn round by the traces, and that they will ſlip off the pins, and be diſengaged during the firſt revolution.

The method of reverſing motion by cauſing pinions to be operated upon by the oppoſite parts of a face-wheel, has been long known and practiſed by mill-wrights; and they have various contrivances for performing the alternation, as by levers, ſcrews, tumbling-bobs, &c. One of theſe will be illuſtrated by a figure, when we come to the article TIDE-*mill*.

As to the ſecond general method, it has perhaps an appearance of greater ſimplicity; though, when reduced to practice, it is commonly found more expenſive than the former. Suppoſe that while the horizontal wheel A (fig. 2. pl. XXVIII.) continues to turn always one way, it is required to have the horizontal wheel B turn, ſometimes in one direction, and ſometimes in another: by means of an additional wheel C, equal in diameter and number of teeth (ſuppoſing the velocities in both directions to be equal), this may be accompliſhed, thus: Let the two wheels B and C have the lower pivots of their axles reſting in boxes or caſes that may be moved up and down by means of ſcrews; and, while the wheels A and B are nearly of equal thickneſs, let the wheel C be ſomewhat more than double the thickneſs of either: when the motion of the wheel B is to be in a contrary direction to that of A, let the wheel C be lowered ſo much that its teeth play neither into thoſe of A nor B, while the teeth of A take into thoſe of B and drive it round: when, on the contrary, B is to be moved in the ſame direction as A, let the wheel B be lowered till its teeth do not come into contact with thoſe of A, and let C be raiſed until the upper parts of its teeth take between thoſe of the wheel A, while the lower parts of other teeth play into the teeth B; ſo ſhall the rotation of B have the direction required. If the motion of the wheel A were ſometimes in one direction and ſometimes in another, the motion of B might all along be preſerved in one direction, by the occaſional application of C as an intermediate wheel.

Regulator *of deſcending motions.* See *Hardie's* **Crane.**

ROTATORY motion, when produced by a reciprocating motion, requires ſome contrivance to render it uniform, or nearly ſo. The uſual method of equalizing is by attaching a fly-wheel to ſome part of the machinery: but Mr. Arthur Woolf has invented an apparatus to be ſubſtituted for the fly in ſteam-engines, which poſſeſſes the advantage of equalizing the motion, with the property of being ſtopped and ſet to work at any part of the ſtroke.

Plate XXIII. fig. 4. A repreſents part of the engine-beam; B the connecting-rod; C the crank-arm; D a cog-wheel, working into another cog-wheel E, of half the ſize; F a crank-arm on the ſhaft of the ſmall wheel; G a cylinder cloſed at bottom, in which a ſolid or unperforated piſton moves, leaving a vacuum beneath. This acts ſimply inſtead of a weight on the crank F, by the conſtant preſſure of the atmoſphere; and the diameter of the piſton muſt be ſuch as nearly to equal one-third of the power of the engine.

In fig. 5. the outer circle is the line deſcribed by the crank; the circumference of the inner circle is equal to twice the diameter of the outer, and the ſquare has the ſame circumference: this laſt exhibits the inequality ſtill remaining, which by this method is reduced to about one fifth; but by the aſſiſtance of a ſmall fly on the ſecond motion, the effect will become nearly the ſame as that of a rotative engine, with the advantages here mentioned.

The ſame motion may be applied to a pump, but in this caſe the two cranks muſt be horizontal at the ſame time. *Nich. Jour.* No. 23. N. S.

SAWMILLS, conſtructed for the purpoſe of ſawing either timber or ſtone, are moved by animals, by water, by wind, or by ſteam. They may be diſtinguiſhed into two kinds: thoſe in which the motion of the ſaws is reciprocating, and thoſe in which the ſaws have a rotatory motion. In either caſe the reſearches of theoriſts have not yet turned to any account: inſtead, therefore, of giving any uncertain theory here, we ſhall proceed to the deſcriptive part, and refer thoſe who wiſh to ſee ſome curious inveſtigations on this ſubject to a Memoir on the Action of Saws, by Euler, in Mem. Acad. Roy. Berlin, 1756.

Reciprocating ſawmills for cutting timber and moved by water, do not exhibit much variety in their conſtruction. The ſawmill repreſented in pl. XXVIII. is taken from Gray's Experienced Millwright; but it only differs in a few trifling particulars from ſome which are deſcribed in Belidor's Architecture Hydraulique, and in Gallon's Collection of Machines approved by the French academy.

1. The plate juſt referred to ſhews the *elevation* of the mill. A A the ſhaft or axle, upon which is fixed the wheel BB (of 17½ or 18 feet diameter), containing 40 buckets to receive the water which impels it round. CC a wheel fixed upon the ſame ſhaft containing 96 teeth, to drive the pinion No. 2. having 22 teeth, which is faſtened upon an iron axle or ſpindle, having a coupling box on each end that turns the cranks, as DD, round: one end of the pole E is put on the crank, and its other end moves on a joint or iron bolt at F, in the lower end of the frame GG. The crank DD being turned round in the pole E, moves the frames GG up and down, and theſe having ſaws in them, by this motion cut the wood. The pinion, No. 2. may work 2, 3, or more cranks, and thus move as many frames of ſaws. No. 3, an iron wheel having angular teeth, which one end of the iron K takes hold of, while its other end rolls on a bolt in the lever HH. One end of this lever moves on a bolt at I, the other end may lie in a notch in the frame GG ſo as to be puſhed up and down by it. Thus the catch K pulls the wheel round, while the catch L falls into the teeth and prevents it from going backwards. (See *Univerſal* LEVER.) Upon the

axle of No. 3. is alſo fixed the pinion No. 4, taking into the teeth in the under edge of the iron bar, that is faſtened upon the frame TT, on which the wood to be cut is laid: by this mean the frame TT is moved on its rollers SS, along the fixed frame UU; and of courſe the wood faſtened upon it is brought forward to the ſaws as they are moved up and down by reaſon of the turning round of the crank DD. VV, the machine and handle to raiſe the ſluice when the water is to be let upon the wheel B B to give it motion. By pulling the rope at the longer arm of the lever M, the pinion No. 2. is put into the hold or grip of the wheel CC, which drives it; and by pulling the rope R, this pinion is cleared from the wheel. No. 5. a pinion containing 24 teeth, driven by the wheel CC, and having upon its axle a ſheave, on which is the rope PP, paſſing to the ſheave No. 6. to turn it round; and upon its axle is fixed the pinion No. 7. acting on the teeth in an iron bar upon the frame TT, to roll that frame backwards when empty. By pulling the rope at the longer arm of the lever N, the pinion No. 5. is put into the hold of the wheel CC; and by pulling the rope O it is taken off the hold. No. 8. a wheel fixed upon the axle No. 9. having upon its periphery angular teeth, into which the catch No. 10. takes; and being moved by the lever attached to the upper part of the frame G, it puſhes the wheel No. 8. round; and the catch No. 11. falls into the teeth of the wheel, to prevent it from going backwards while the rope rolls in its axle, and drags the logs or pieces of wood in at the door Y, to be laid upon the moveable frames TT, and carried forward to the ſaws to be cut. The catches No. 10. 11. are eaſily thrown out of play when they are not wanted. The gudgeons in the ſhafts, rounds of the cranks, ſpindles, and pivots, ſhould all turn round in cods or buſhes of braſs. Z, a door in one end of the mill-houſe at which the wood is conveyed out when cut. WW, walls of the mill-houſe. QQ, the couples or framing of the roof. XXX, &c. windows to admit light to the houſe.

A plan of this mill is given in pl. 43. of Mr. Gray's book.

2. Sawmills for cutting blocks of ſtone are generally, though not always, moved horizontally: the horizontal alternate motion may be communicated to one or more ſaws, by means of a rotatory motion, either by the uſe of cranks, &c. or in ſome ſuch way as the following. Let the horizontal wheel ABDC (fig. 3. pl. XX.) drive the pinion O*p*N, this latter carrying a vertical pin P, at the diſtance of about $\frac{1}{3}$ of the diameter from the centre. This pinion and pin are repreſented ſeparately in No. 2. of fig. 3. Let the frame WSTV, carrying four ſaws, marked 1, 2, 3, 4, have wheels V,T,W,W, each running in a groove or rut, whoſe direction is parallel to the propoſed

direction of the ſaws: and let a tranſverſe groove PR, whoſe length is double the diſtance of the pin P from the centre of the pinion, be cut in the ſaw frame to receive that pin. Then, as the great wheel revolves, it drives the pinion, and carries round the pin P; and this pin, being compelled to ſlide in the ſtraight groove PR, while by the rotation of the pinion on which it is fixed its diſtance from the great wheel is conſtantly varying, it cauſes the whole ſaw frame to approach to and recede from the great wheel alternately, while the grooves in which the wheels run confine the frame ſo as to move in the direction T*t*, V*v*. Other blocks of ſtone may be ſawn at the ſame time by the motion of the great wheel, if other pinions and frames running off in the directions of the reſpective radii EB, EA, EC, be worked by the teeth at the quadrantal points B, A, and C. And the contrary efforts of theſe four frames and pinions will tend to ſoften down the jolts, and equalize the whole motion.

The ſame contrivance, of a pin fixed at a ſuitable diſtance from the centre of a wheel, and ſliding in a groove, may ſerve to convert a reciprocating into a rotatory motion: but it will not be preferable to the common converſion by means of a crank.

3. When ſaws are uſed to cut blocks of ſtone into pieces having cylindrical ſurfaces, a ſmall addition is made to the apparatus. See figs. 8, 9. pl. XX. The ſaw, inſtead of being allowed to fall in a vertical groove as it cuts the block, is attached to a lever or beam FG, ſufficiently ſtrong; this lever has ſeveral holes pierced through it, and ſo has the vertical piece ED, which is likewiſe moveable towards either ſide of the frame in grooves in the top and bottom pieces AL, DM. Thus, the length KG of the radius can be varied at pleaſure, to ſuit the curvature of NO; and as the ſaw is moved to and fro by proper machinery, in the direction CB, BC, it works lower and lower into the block, while, being confined by the beam FG, it cuts the cylindrical portion from the block P, as required.

When a completely cylindrical pillar is to be cut out of one block of ſtone, the firſt thing will be to aſcertain in the block the poſition of the axis of the cylinder; then lay the block ſo that ſuch axis ſhall be parallel to the horizon, and let a cylindrical hole of from one to two inches diameter be bored entirely through it. Let an iron bar, whoſe diameter is rather leſs than that of this tube, be put through it, having juſt room to ſlide freely to and fro as occaſion may require. Each end of this bar ſhould terminate in a ſcrew, on which a nut and frame may be faſtened; the nut frame ſhould carry three flat pieces of wood or iron, each having a ſlit running along its middle nearly from one end to the other, and a ſcrew and handle muſt be adapted to each ſlit: by theſe means the frame-work at each end of the bar may readily be ſo adjuſted as to form equal iſoſceles or equilateral triangles; the iron bar will connect two correſponding angles of theſe triangles, the ſaw to be uſed two other correſponding angles, and another bar of iron or of wood the two remaining angles, to give ſufficient ſtrength to the whole frame. This conſtruction, it is obvious, will enable the workmen to place the ſaw at any propoſed diſtance from the hole drilled through the middle of the block; and then, by giving the alternating motion to the ſaw frame, the cylinder may at length be cut from the block, as required. This method was firſt pointed out in the Collection of Machines approved by the Paris academy.

If it were propoſed to ſaw a conic fruſtum from ſuch a block, then let two frames of wood or iron be fixed to thoſe parallel ends of the block which are intended to coincide with the baſes of the fruſtum, circular grooves being previouſly cut in theſe frames to correſpond with the circumferences of the two ends of the propoſed fruſtum; the ſaw being worked in theſe grooves will manifeſtly cut the conic ſurface from the block. This, we believe, is the contrivance of ſir George Wright.

The beſt method of drilling the hole through the middle of the propoſed cylinder ſeems to be this: on a carriage running upon four low wheels let two vertical pieces (each having a hole juſt large enough to admit the borer to play freely) be fixed two or three feet aſunder, and ſo contrived that the pieces and holes to receive the borer may, by ſcrews, &c. be raiſed or lowered at pleaſure, while the borer is prevented from ſliding to and fro by ſhoulders upon its bar, which are larger than the holes in the vertical pieces, and which, as the borer revolves, preſs againſt thoſe pieces: let a part of the boring bar between the two vertical pieces be ſquare, and a grooved wheel with a ſquare hole of a ſuitable ſize be placed upon this part of the bar; then the rotatory motion may be given to the bar by an endleſs band which ſhall paſs over this grooved wheel and a wheel of a much larger diameter in the ſame plane, the latter wheel being turned by a winch handle in the uſual way. As the boring proceeds, the carriage with the borer may be brought nearer and nearer the block, by levers and weights, in the ſame manner as is deſcribed under the article *boring of* ORDNANCE.

4. Circular ſaws, acting not by a reciprocating, but by a rotatory, motion, have been long known in Holland, where they are uſed for cutting wood uſed in veneering. They were introduced into this country, we believe, by general Bentham, and are now uſed in the dock-yard at Portſmouth, and in a few

other places: but they are not, as yet, ſo generally adopted as might be wiſhed, conſidering how well they are calculated to abridge labour, and to accompliſh with expedition and accuracy what is very tedious and irkſome to perform in the uſual way. Circular ſaws may be made to turn either in horizontal, vertical, or inclined, planes; and the timber to be cut may be laid upon a plane inclined in any direction; ſo that it may be ſawn by lines making any angle whatever, or at any propoſed diſtance from each other. When the ſaw is fixed at a certain angle, and at a certain diſtance from the edge of the frame, all the pieces will be cut of the ſame ſize, without marking upon them by a chalked line, merely by cauſing them to be moved along and keeping one ſide in contact with the ſide of the frame; for then, as they are brought one by one to touch the ſaw revolving on its axle, and are preſſed upon it, they are ſoon cut through.

Mr. Smart, of Ordnance Wharf, Weſtminſter-bridge, has ſeveral circular ſaws, all worked by a horſe in a moderate ſized walk: one of theſe, intended for cutting and boring tenons uſed in this gentleman's hollow maſts, is repreſented in fig. 2. pl. XXVI. NOPQR is a hollow frame, under which is part of the wheel-work of the horſe-mill.—A, B, D, C, E, F, are pulleys, over which paſs ſtraps or endleſs bands, the parts of which out of ſight run upon the rim of a large vertical wheel: by means of this ſimple apparatus, the ſaws S, S′, are made to revolve upon their axles with an equal velocity, the ſame band paſſing round the pulleys D, C, upon thoſe axles; and the rotatory motion is given to the borer G by the band paſſing over the pulley A. The board I is inclined to the horizon in an angle of about 30 degrees; the plane of the ſaw S′ is parallel to that of the board I, and about ¼ of an inch diſtant from it, while the plane of the ſaw S is vertical, and its loweſt point at the ſame diſtance from the board I. Each piece of wood K out of which the tenon is to be cut is 4 inches long, an inch and a quarter broad, and ⅕ of an inch thick. One end of ſuch piece is laid ſo as to ſlide along the ledge at the lower part of the board I; and as it is puſhed on, by means of the handle H, it is firſt cut by the ſaw S′, and immediately after by the ſaw S: after this the other end is put loweſt, and the piece is again cut by both ſaws: then the tenon is applied to the borer G, and as ſoon as a hole is pierced through it, it is dropped into the box beneath. By this proceſs, at leaſt 30 tenons may be completed in a minute, with greater accuracy than a man could make *one* in a quarter of an hour, with a common hand-ſaw and gimblet. The like kind of contrivance may, by ſlight alterations, be fitted for many other purpoſes, particularly all ſuch as may require the ſpeedy ſawing of a great number of pieces into exactly the ſame ſize and ſhape. A very great advantage attending this ſort of machinery is, that, when once the poſition of the ſaws and frame is adjuſted, a common labourer may perform the buſineſs juſt as well as the beſt workman.

SCAPEMENT, from the French word *echappement*, a term uſed among clock and watch-makers, to denote the general contrivance by which the preſſure of the wheels, which move always in one direction, and the reciprocating motion of the pendulum or balance, are accommodated the one to the other. When a tooth of a wheel has given the balance or pendulum a motion in one direction, it muſt quit it, that it may get an impulſion in the oppoſite direction; and it is this *eſcaping* of the tooth of the wheel from the balance or pendulum, or of the latter from the former, whichever we pleaſe to call it, that has given riſe to the general term.

From the nature of a pendulum, it follows, that it need only to be removed from the vertical, and then let go, in order to vibrate and meaſure time. Hence it might ſeem that nothing is wanted but a machinery ſo connected with the pendulum as to keep a regiſter, as it were, of the vibration. It could not be difficult to contrive a method of doing this; but more is wanted: the air muſt be diſplaced by the pendulum. This requires ſome force, and muſt therefore employ ſome part of the momentum of the pendulum. The pivot on which it ſwings occaſions friction—the thread, or thin piece of metal by which it is hung, in order to avoid this friction, occaſions ſome expenditure of force by its want of perfect flexibility or elaſticity. Theſe, and other cauſes, make the vibrations grow more and more narrow by degrees, till at laſt the pendulum is brought to reſt. We muſt, of courſe, have a contrivance in the wheelwork which will reſtore to the pendulum the ſmall portion of force which it loſes in every vibration. The action of the wheels therefore may be called a *maintaining power*, becauſe it keeps up the vibrations. But this may affect the regularity of vibration. If it be ſuppoſed that the action of gravity renders all the vibrations iſochronous, we muſt grant that the additional impulſion by the wheels will deſtroy that iſochroniſm, unleſs it be ſo applied that the ſum total of this impulſion and the force of gravity may vary ſo with the ſituation of the pendulum as ſtill to give a ſeries of forces, or a law of variation, perfectly ſimilar to that of gravity. This cannot be effected, unleſs we know both the law which regulates the action of gravity, producing iſochroniſm of vibration, and the intenſity of the force to be derived from the wheels in every ſituation of the pendulum.

Thus it appears that conſiderable ſcientific ſkill as well as mechanical ingenuity may be diſplayed in the conſtruction of ſcapements; and the judicious conſideration of them becomes of great importance to the artiſt: yet, notwithſtanding this, no material improvement was made in them from the firſt application of the pendulum to clocks till the days of Mr. George Graham; nothing more was attempted before his time than to apply the impulſe of the ſwing-wheel, in ſuch manner as was attended with the leaſt friction, and would give the greateſt motion to the pendulum. Dr. Halley diſcovered, by ſome experiments made at the Royal Obſervatory at Greenwich, that by adding more weight to the pendulum, it was made to vibrate larger arcs, and the clock went faſter; by diminiſhing the weight of the pendulum, the vibrations became ſhorter, and the clock went ſlower: the reſult of theſe experiments being diametrically oppoſite to what ought to be expected from the theory of the pendulum, probably firſt rouſed the attention of Mr. Graham, who was not only ſkilful in practice, but had much mathematical knowledge, and was well qualified to examine the ſubject ſcientifically: he ſoon made ſuch further trials as convinced him, that this ſeeming paradox was occaſioned by the retrograde motion, which was given to the ſwing-wheel by every conſtruction of ſcapement that was at that time in uſe; and his great ſagacity ſoon produced a remedy for this defect, by conſtructing a ſcapement which prevented all recoil of the wheels, and reſtored to the clock pendulum, wholly in theory, and nearly in practice, all its natural properties in its detached ſimple ſtate. This ſcapement, with a few others of the moſt approved conſtruction, will now be briefly deſcribed.

1. The ſcapement which has been in uſe for clocks and watches ever ſince their firſt appearance in Europe is extremely ſimple; and its mode of operation is too obvious to need much explanation. In fig. 1. pl. XXIX. XY repreſents a horizontal axis, to which the pendulum P is attached by a ſlender rod, or otherwiſe. This axis has two leaves C and D attached, one near each end, and not in the ſame plane, but ſo that when the pendulum hangs perpendicularly, and at reſt, the piece C inclines a few degrees to the right hand, and D as much to the left. They commonly make an angle of from 70 to 90 degrees: they are called by the name of *pallets*. AFB repreſents a wheel turning round on a perpendicular axis EO, in the order of the letters AFEB. The teeth of this wheel are cut into the form of the teeth of a ſaw, leaning forward, in the direction of the motion of the rim. As they ſomewhat reſemble the points of an old-faſhioned royal diadem, this wheel has got the name of the *crown-wheel*. In watches it is often called the *balance-wheel*. The number of the teeth is generally odd; ſo that when one of them B is preſſing on a pallet D, the oppoſite pallet C is

in the ſpace between two teeth A and I. The figure repreſents the pendulum at the extremity of its excurſion to the right hand, the tooth A having juſt eſcaped from the pallet C, and the tooth B having juſt dropped on the pallet D. It is plain, that as the pendulum now moves over to the left, in the arch PG, the tooth B continues to preſs on the pallet D, and thus accelerates the pendulum, both during its deſcent along the arch PH, and its aſcent along the arch HG. It is no leſs evident, that when the pallet D, by turning round the axis XY, raiſes its point above the plane of the wheel, the tooth B eſcapes from it, and I drops on the pallet C, which is now nearly perpendicular. I preſſes C to the right, and accelerates the motion of the pendulum along the arch GP. Nothing can be more obvious than this action of the wheel in maintaining the vibrations of the pendulum. We can eaſily perceive, alſo, that when the pendulum is hanging perpendicularly in the line XH, the tooth B, by preſſing on the pallet D, will force the pendulum a little way to the left of the perpendicular, and will force it ſo much the further as the pendulum is lighter; and, if it be ſufficiently light, it will be forced ſo far from the perpendicular that the tooth B will eſcape, and then I will catch on C, and force the pendulum back to P, where the whole operation will be repeated. The ſame effect will be produced in a more remarkable degree, if the rod of the pendulum be continued through the axis XY, and a ball Q put on the other end to balance P. And, indeed, this is the contrivance which was firſt applied to clocks all over Europe, before the application of the pendulum. They were *balance* clocks. The force of the wheel was of a certain magnitude, and therefore able, during its action on a pallet, to communicate a certain quantity of motion and velocity to the balls of the balance. When the tooth B eſcapes from the pallet D, the balls are then moving with a certain velocity and momentum. In this condition, the balance is checked by the tooth I catching on the pallet C. But it is not inſtantly ſtopped. It continues its motion a little to the left, and the pallet C forces the tooth I a little backward. But it cannot force it ſo far as to eſcape over the top of the tooth I; becauſe all the momentum of the balance was generated by the force of the tooth B; and the tooth I is equally powerful. Beſides, when I catches on C, and C continues its motion to the left, its lower point applies to the face of the tooth I, which now acts on the balance by a long and powerful lever, and ſoon ſtops its further motion in that direction; and now, continuing to preſs on C, it urges the balance in the oppoſite direction. Thus we ſee that in a ſcapement of this kind the motion of the wheel muſt be very hobbling and unequal, making a great ſtep forward, and a ſhort ſtep backward, at every beat. This has occaſioned the contrivance to get the name of the *recoiling ſcapement*, or the *ſcapement of recoil*.

In this ſcapement the vibrations are quicker than if the balance or pendulum vibrated freely: for the recoil ſhortens the aſcending part of the vibration, by contracting the extent of the arc, and the re-action of the wheel accelerates the deſcending part of the vibration. In this ſcapement, too, if the maintaining power be increaſed, the vibrations will be performed in larger arcs, but in leſs time: becauſe the greater preſſure of the crown-wheel on the pallet will cauſe the balance to vibrate through larger arches; and the time will be leſs increaſed on this account than it will be diminiſhed by the acceleration that preſſure gives to the balance and the diminution of the time of recoil.

2. The preceding ſcapement not being well adapted to ſuch vibrations as are performed through arcs of a few degrees only, another conſtruction has been made which has been in conſtant uſe for about a century in clocks, with a long pendulum beating ſeconds. In fig. 2. AB repreſents a vertical wheel called the ſwing-wheel, having thirty teeth. CD repreſents a pair of pallets connected together, and moveable in conjunction with the pendulum on the centre or axis F. One tooth of the wheel, as ſhewn in the figure, reſts on the inclined ſurface of the inner part of the pallet C; on which its diſpoſition to ſlide tends to throw the point of the pallet further from the centre of the wheel, and conſequently aſſiſts the vibration in that direction. While the pallet C moves outwards and the wheel advances, the point of the pallet D of courſe approaches towards the centre in the opening between the two neareſt teeth; and when the acting tooth of the wheel ſlips off, or eſcapes from the pallet C, another tooth on the oppoſite ſide immediately falls on the exterior inclined face of D, and by a ſimilar operation tends to puſh that pallet from the centre. The returning vibration is thus aſſiſted by the wheel, while the pallet C moves towards the centre, and receives the ſucceeding tooth of the wheel, after the eſcape from the point of D. Thus may the alternation be conceived to go on without limit.

In this ſcapement, as well as the former, the vibrating part is conſtantly under the influence of the maintaining power, except during the interval of the drop, or actual eſcape of the wheel from one pallet to the other. One principal recommendation of this ſcapement ſeems to have been the facility with which it affords an index for ſeconds in the face of the clock. Though the pendulum, according to this conſtruction, is conſtantly connected with the maintaining power in a clock, yet the variations of that power have not the ſame miſchievous effect as in a watch, becauſe the momentum of the pendulum, compared with the impulſe of the maintaining power, is prodigiouſly greater in the former of theſe inſtruments. A very conſiderable change in the maintaining power of a clock with a long pendulum will only cauſe a variation of a few ſeconds in the daily rate.

3. Mr. Graham's ſcapement, already ſpoken of, was a conſiderable improvement upon that juſt deſcribed. He took off part of the ſlope furtheſt from the points of the pallets; and inſtead of that part he formed a circular or cylindrical face, having its axis in the centre of motion. Pallets of this kind are ſhewn at the lower part of fig. 2. at E and G, having H for their centre or axis. A tooth of the wheel is ſeen reſting upon the circular inner ſurface of the pallet G, which therefore is not affected by the wheel, excepting ſo far as its motion, ariſing from any other cauſe, may be affected by the friction of the tooth; and this reſiſtance is exceedingly minute, not amounting to one-eighth of the preſſure on the arch. Nay, we think it appears from the experiments of Coulomb, that, in the caſe of ſuch minute preſſures on a ſurface covered with oil, there is no ſenſible retardation analogous to that produced by friction, and that what retardation we obſerve ariſes entirely from the clamminеſs of the oil. If the vibration of the pendulum be ſuppoſed to carry G outwards, the ſlope ſurface will be brought to the point of the tooth, which will ſlide along it, and urge the pallet outwards during this ſliding action. When the tooth has fallen from the point of this pallet, an oppoſite tooth will be received on the circular ſurface of E, and will not affect the variation, excepting when the ſlope ſurface of E is carried out ſo as to ſuffer the tooth to ſlide along it. This contrivance is known by the name of the *dead beat*, the *dead ſcapement*; becauſe the ſeconds index ſtands ſtill after each drop, whereas the index of a clock with a recoiling ſcapement is always in motion, hobbling backward and forward.

In this ſcapement, an increaſe of the maintaining power renders the vibrations larger and ſlower: becauſe the greater preſſure of the tooth on the edge of the pallet throws it round through a greater arch; and its increaſed preſſure on both ſurfaces of the pallet retards its motion.

4. The effect of the ſcapement which has been called horizontal, becauſe the laſt wheel in watches of this conſtruction has its plane parallel to the reſt of the ſyſtem, is ſimilar to that of the dead-beat ſcapement of Graham. In fig. 5, the horizontal wheel is ſeen with twelve teeth, upon each of which is fixed a ſmall wedge ſupported above the plane of the wheel, as

may be ſeen at the letters A and B. On the verge of the balance there is fixed part of a hollow cylinder of ſteel or other hard material, the imaginary axis of which paſſes through the pivots of the verge. C repreſents this cylindrical piece, into which the verge D may be ſuppoſed to have fallen. While the vibration cauſes the cylindrical piece to revolve in the direction which carries its anterior edge towards the axis of the wheel, the point of the wedge will merely rub the internal ſurface, and no otherwiſe affect the vibration of the balance than by retarding its motion. But when the return of the vibration clears the cylinder of the point of the wedge D, the wheel will advance, and the ſlope ſurface of the wedge acting againſt the edge of the cylinder will aſſiſt the vibration of the balance. When the edge of the cylinder arrives at the outer point of the wedge D, its poſterior edge muſt arrive at the poſition denoted by the dotted lines of continuation; immediately after which the wedge or tooth E will arrive at the poſition *e*, and reſt on the outer ſurface of the cylinder, where it will produce no other effect than that of retardation from friction, as was remarked with regard to the wedge D, until the courſe of the vibration ſhall bring the poſterior edge of the cylinder clear of the point of the wedge. In this laſt ſituation, the wedge will act on the edge of the cylinder, and aſſiſt the vibration, as in the former caſe, until that edge ſhall arrive at the outer or poſterior point of the wedge; immediately after which the leading point will fall on the inner ſurface of the cylinder in the firſt poſition, as was ſhewn in the wedge D.

Horizontal watches were greatly eſteemed during the laſt thirty years, until lately, when they gave place to thoſe conſtructions which are known by the name of detached or free ſcapements. In the common ſcapement, fig. 1, an increaſe of the maintaining power increaſes the recoil, and accelerates the vibrations: but with the horizontal ſcapement there is no recoil; and an increaſe of the maintaining power, though it may enlarge the arc of vibration, will not neceſſarily diminiſh or alter the time. It is accordingly found, that the experiment of altering the maintaining power by the application of the key does not alter the rate in the ſame perceptible manner as in common watches.

5. Fig. 6, repreſents the free ſcapement of our beſt portable time-pieces. Fig. 4, exhibits the ſcapement on a large ſcale. On the verge of the balance is fixed a circular piece of ſapphire, or of hard ſteel, EL, out of which a ſectoral piece is cut. HG is a ſtraight ſpring fixed near its extremity H, and having at the other extremity a pin G, againſt which one of the teeth of the wheel D reſts when the train is at reſt. This ſpring has a ſlight

tendency towards the centre of the wheel, but is prevented by the ſtop K from throwing the pin further inwards than juſt to receive the point of the tooth. I is a very ſlender ſpring fixed at the end I, and preſſing very ſlightly againſt the pin G, in a direction tending to throw it from the wheel D, but which on account of the greater power of HG it cannot effect. It may be obſerved that the ſpring I proceeds a little beyond the pin G.—F is a lever proceeding from the verge of the balance directly oppoſite the end of the ſpring I, and long enough to ſtrike it in its vibration. The action is as follows:—From the preſſure of the main ſpring the wheel (fig. 4.) is urged from D towards F, but is prevented from moving by the pin G. Let the balance be made to vibrate, and the lever F will move through the arc F*f*, ſtrike the inner extremity of the ſpring I, and diſplace the pin G. At this inſtant the face E, which may be called the pallet, will have arrived at the poſition *e*, againſt which the tooth of the wheel will fall, and communicate its impulſe through about 15° or 16° of the vibration. But F quits the ſpring I ſooner than the wheel quits the pallet E, and conſequently the pin G will have returned to its firſt ſtation before the wheel can have advanced a whole tooth, and the ſpring or detent HG will receive the wheel as before, immediately after its eſcape from the pallet. The returning vibration of the balance will be made with the piece EL perfectly at liberty between two teeth of the wheel, as in the ſketch, and the back ſtroke of the lever F againſt the tender ſpring I will have no effect whatever on the pin G; this ſpring being like the back ſpring of the jacks of the harpſichord, active in one direction only. The third vibration of the balance will unlock the detent as before; the impulſe will again be given, and the whole proceſs will be repeated: and in this manner, the balance, though it may vibrate through the greateſt part of the entire circle, will be entirely free of the works, except during the very ſmall time of the drop of the wheel.

It is hardly neceſſary to make any remark on this ſcapement. It requires little or no oil; and when all the parts, particularly the pendulum ſpring, are duly adjuſted, it is found that a very great variation in the firſt mover will remarkably alter the arc of vibration without affecting the rate. The piece EL might have conſiſted of a ſingle pallet or arm, inſtead of a portion of a circle or cylinder; but ſuch a piece would have been rather leſs convenient to make in ſapphire, or ruby, as in the beſt time-pieces, and would alſo have been leſs uſeful. For if by any accident or ſhock the pin G ſhould be diſplaced for an inſtant, the wheel D will not run down, becauſe it will be caught upon the circular ſurface of EL. It is indeed very eaſy to obſerve, that the piece EL would operate without the detent, though with much friction during the time of repoſe. The tooth of the wheel would in that caſe reſt upon its circular face.

6. In the two laſt ſcapements we have ſeen the variable effects of the maintaining power almoſt entirely removed, as far as can be practically diſcerned. Fig. 7, exhibits the ſcapement of Mudge; in which the balance is perfectly detached from the train of wheels, except during the extremely ſhort interval of ſtriking out the parts which ſerve the purpoſe of detents. ONEBQ is the circumference of the balance, vibrating by the action of a ſpiral ſpring as uſual on its axis CA DH paſſing through the centre C: the axis is bent into a crank, AXYD, to make room for the other work. LM, ZW, are two rods fixed to the crank at the points L and Z, parallel to XY. $c\,d\,e\,f\,r\,s$ are fixed parts of the machine. TR is an axis concentric with that of the balance, and carrying an arm Go nearly at right angles to it, and a ſmall auxiliary ſpring u, which is wound up whenever the arm Go is moved in the direction oh. p is a curved pallet fixed to the axis TR, which receives the tooth of the balance wheel near the axis. The tooth, proceeding along the curved ſurface, by the force of the main ſpring turns the axis and its arm Go, and winds up the ſpring u. A ſmall projection at the extremity of the curved ſurface of the pallet p prevents the further progreſs of the tooth, when the arm oG has been turned through an arc oh, of about 27°; and conſequently the ſpring u has been wound up through the ſame angle or arc, $o\mathrm{G}h = 27^{\circ}$.——FS is another axis exactly ſimilar to TR. It carries its arm Io, and ſpring v, and the tooth of the balance-wheel lm winds up the ſpring v, by acting on the pallet q, and is detained by a projection, after having carried it through an angle of 27°, exactly as in the former caſe. The arcs paſſed through by the arms Go and Io, and marked in the figure, are alſo denoted by the ſame letters on the rim of the balance.

The effect of this ſcapement may be thus explained: let the balance be in the quieſcent ſtate, the main ſpring being unwound, and the branch or crank in the poſition repreſented in the figure. If the quieſcent points of the auxiliary ſprings coincide with that of the balance-ſpring, the arm Go will juſt touch the rod LM, and in like manner the arm Io will juſt touch the rod WZ; the two arms Go and Io in this poſition are parallel to the line CO. This poſition of the balance and auxiliary ſprings remains as long as the main ſpring of the machine continues unwound; but whenever the action of the main ſpring ſets the balance-wheel in motion, a tooth thereof meeting with one or other of the pallets p or q, will wind up one of the auxiliary ſprings: ſuppoſe it ſhould be the ſpring *u*. The arm G*o* being carried into the poſition G*b*, by the force of the balance-wheel acting on the pallet *p*, remains in that poſition as long as the tooth of the balance-wheel continues locked by the projection at the extremity of the pallet *p*; and the balance itſelf not being at all affected by the motion of the arm G*o*, nor by the winding up of the ſpring *u*, remains in its quieſcent poſition: conſequently no vibration can take place, except by the aſſiſtance of ſome external force to ſet the balance in motion. Suppoſe an impulſe to be given ſufficient to carry it through the ſemi-arc OB, which is about 135° in Mr. Mudge's conſtruction.

The balance, during this motion, carries with it the crank AXYD, and the affixed rods LM, ZW. When the balance has deſcribed an angle of about 27° = the angle *o*C*b*, or *o*G*b*, the rod LM meets with the arm GH, and by turning the axis TR, and the pallet *p* in the direction of the arc *o b*, releaſes the tooth of the balance-wheel from the projection at the extremity of the pallet *p*: the balance-wheel immediately revolves; and the lower tooth meeting with the pallet *q*, winds up the auxiliary ſpring *v*, and carries the arm I*o* with a circular motion through the angle *o*I*k*, about 27°, in which poſition the arm I*o* remains as long as the tooth of the balance-wheel is locked by the pallet *q*. While the ſpring *v* is winding up through the arc *o k*, the balance deſcribes the remaining part of the ſemi-arc *b*B, and during this motion the rod LM carries round the arm G*b*, cauſing it to deſcribe an angle *b*CB, or *b*GB, which is meaſured by the arc *b*B = 108°. When the balance has arrived at the extremity of the ſemi-arc OB = 135°, the auxiliary ſpring *u* will have been wound up through the ſame angle of 130°, that is to ſay, 27°, by the force of the main-ſpring acting on the pallet *p*, and 108° by the balance itſelf, carrying along with it the arm G*o*, or G*b*, while it deſcribes the arc *b*B. The balance therefore returns through the arc BO, by the joint action of the balance-ſpring and the auxiliary ſpring *u*; the acceleration of both ſprings ceaſing the inſtant the balance arrives at the quieſcent point *o*. When the balance has proceeded in its vibration about 27° beyond the point O, to the poſition C*k*, the rod ZW meets with the arm I*k*, and by carrying it forward releaſes the tooth of the balance-wheel from the pallet *q*. The balance-wheel accordingly revolves, and the upper tooth meeting with the pallet *p* winds up the auxiliary ſpring *u* as before. The balance with the crank proceeding to deſcribe the remaining ſemi-arc *k*E, winds up the ſpring *v* through the further angle *k*CE = 108°, and returns through the ſemi-arc E*o*, by the joint action of the balance-ſpring and the auxiliary ſpring *v*, both of which ceaſe to accelerate the balance the inſtant it has arrived at O.

It may be remarked, in this curious ſcapement, that the motion of the balance in its ſemi-vibration from the point of quieſcence is oppoſed through an arc of no more than 108, but is accelerated in its return through the whole arc of 135°, and that the difference is what maintains the vibrations; and moreover, that the force from the wheel being exerted to wind up each auxiliary ſpring during the time it is totally diſengaged from the balance, this laſt organ cannot be effected by its irregularities, except ſo far as they may render it more difficult to diſengage the rim of the pallet from the tooth. The balance deſcribes an arc of about 8° during this diſengagement.

Count Bruhl, in his pamphlet "On the Inveſtigation of Aſtronomical Circles," after deſcribing Mudge's ſcapement, proceeds thus: "By what has been ſaid, it is evident, that whatever inequality there may be in the power derived from the main ſpring (provided the latter be ſufficient to wind up thoſe little pallet-ſprings), it can never interfere with the regularity of the balance's motion, but at the inſtant of unlocking the pallets, which is ſo inſtantaneous an operation, and the reſiſtance ſo exceedingly ſmall, that it cannot poſſibly amount to any ſenſible error. The removal of this great obſtacle was certainly never ſo effectually done by any other contrivance, and deſerves the higheſt commendation, as a probable means to perfect a portable machine that will meaſure time correctly. But this is not the only, nor indeed the principal, advantage which this time-keeper will poſſeſs over any other; for, as it is impoſſible to reduce friction to ſo ſmall a quantity as not to affect the motion of a balance, the conſequence of which is, that it deſcribes ſometimes greater and ſometimes ſmaller arcs, it became neceſſary to think of ſome method by which the balance might be brought to deſcribe thoſe different arcs in the ſame time. If a balance could be made to vibrate without friction or reſiſtance from the medium in which it moves, the mere expanding and contracting of the pendulum-ſpring would probably produce the ſo much wiſhed for effect, as its force is ſuppoſed to be proportional to the arcs deſcribed; but as there is no machine void of friction, and as from that cauſe, the velocity of every balance decreaſes more rapidly than the ſpaces gone through decreaſe, this inequality could only be removed by a force acting on the balance, which aſſuming different ratios in its different ſtages, could counterbalance that inequality. This very material and important remedy, Mr. Mudge has effected by the conſtruction of his ſcapement; for his pallet-ſprings having a force capable of being increaſed almoſt at pleaſure, at the commencement of every vibration, the proportion in their different degrees of tenſion may be altered till it anſwers the intended purpoſe. This ſhews how effectually Mr. Mudge's ſcapement removes the two greateſt difficulties that have hitherto baffled the attempts of every other artiſt, namely, the inequalities of the power derived from the main ſpring, and the irregularities ariſing from friction, and the variable reſiſtance of the medium in which the balance moves."

7. Fig. 8, is the ſketch of an adaptation of Mudge's ſcapement to a clock. LM is a part of the periphery of the wheel. GA, GB, are two arms ſeparately moveable on the ſame axis, and terminating in the pallets A, B. Theſe pallets have inclined faces, with a claw or detent at the lower part of each. GO, IO, are tails proceeding from each pallet-piece reſpectively, and the dark ſpot at N repreſents a pin proceeding from the pendulum rod, and capable of moving either of the tails according to the courſe of the vibration. The dotted circles *u* and *v* repreſent weights which are ſtuck upon two pins, and may be changed for others, greater or ſmaller, until the moſt ſuitable quantity is found. Suppoſe the wheel to be urged from L towards M, and the pendulum made to vibrate by external impulſe. The pin N proceeding towards L will ſtrike the tail GO, raiſe the pallet A, and ſet the wheel at liberty: which ſliding along the inner ſurface of the pallet B, will raiſe it, and ſtop againſt the claw at its lower end. IO will conſequently be carried into the poſition IP; and the pallet A in its return will be oppoſite a vacancy, which will permit the tail GO to follow the pin N as far as the perpendicular ſituation. The pendulum will therefore be aſſiſted by the weight *u* through a longer arc in its deſcent, than it was impeded by it in its aſcent. In the oppoſite ſemi-vibration toward M, the pendulum will proceed unoppoſed by *v*, while it paſſes through the angle OIP, when it will raiſe B, and permit the wheel to elevate the pallet A. In the motion on this ſide of the perpendicular, it is alſo clear that the deſcent will be more aſſiſted than the aſcent was impeded. Whence it follows, that the clock will continue to go: and no variation of the force of the wheel LM, which raiſes the pallets in the abſence of the pendulum, will affect the vibration, except ſo far as it may afford a variable reſiſtance at the detent or claw.

8. Mr. Mudge has alſo given another detached ſcapement, which he recommends for pocket-watches, and executed entirely to his ſatisfaction in one made for the queen. A dead-beat pendulum ſcapement is interpoſed between the wheels and the balance. The crutch EDF (fig. 3.) has a third arm

DG ſtanding outwards from the meeting of the other two, and of twice their length. This arm terminates in a fork AGB. The verge V has a pallet C, which, when all is at reſt, would ſtand between the points A, B, of the fork. But the wheel, by its action on the pallet E, forces the fork into the poſition B *g b*, the point A of the fork being now where B was before, juſt touching the cylindrical ſurface of the verge. The ſcapement of the crutch EDF is not accurately a dead-beat ſcapement, but has a very ſmall recoil beyond the angle of impulſion. By this circumſtance the branch A (now at B) is made to preſs moſt gently on the cylinder, and keeps the wheel locked, while the balance is going round in the direction BHA. The point A gets a motion from A to B by means of a notch in the cylinder, which turns round at the ſame time by the action of the branch AG on the pallet C; but A does not touch the cylinder during this motion, the notch leaving free room for its paſſage. When the balance returns from its excurſion, the pallet C ſtrikes on the branch A (ſtill at B), and unlocks the wheel. This now acting on the crutch-pallet F, cauſes the branch *b* of the fork to follow the pallet C, and give it a ſtrong impulſe in the direction in which it is then moving, cauſing the balance to make a ſemi-vibration in the direction AHB. The fork is now in the ſituation A *g a*, ſimilar to B *g b*, and the wheel is again locked on the crutch-pallet E.

‘The intelligent reader will admit this to be a very ſteady and effective ſcapement. The lockage of the wheel is procured in a very ingenious manner; and the friction on the cylinder, neceſſary for effecting this, may be made as ſmall as we pleaſe, notwithſtanding a very ſtrong action of the wheel: for the preſſure of the fork on the cylinder depends entirely on the degree of recoil that is formed on the pallets E and F. *Preſſure* on the cylinder is not indiſpenſably neceſſary, and the crutch-ſcapement might be a real dead-beat. But a ſmall recoil, by keeping the fork in contact with the cylinder, gives the moſt perfect ſteadineſs to the motion. The ingenious inventor, a man of approved integrity and judgment, declares that her majeſty's watch was the beſt pocket-watch he had ever ſeen. We are not diſpoſed to queſtion its excellency.

9. Another ſcapement, in which a conſiderable degree of ingenuity is united with comparative ſimplicity is that of Mr. De Lafons. “The inventor's deſcription, and ſome of his obſervations, as preſented to the Society of Arts, are as follows:

“Although the giving an equal impulſe to the balance has been already moſt ingeniouſly done by Mr. Mudge and Mr. Haley (from whoſe great merit I would not wiſh to detract), yet the extreme difficulty and expence attending the firſt, and the very compound locking of the ſecond, render them far from completing the deſired object.

" The perfections and advantages ariſing from my improvements on the remontoire detached ſcapement for chronometers, which gives a perfectly equal impulſe to the balance, and not only entirely removes whatever irregularities ariſe from the different ſtates of fluidity in the oil, from the train of wheels, or from the main ſpring, but does it in a ſimpler way than any with which I am acquainted. I truſt it will not be thought improper in me to anſwer ſome objections made at the examinations before the committee, as I am fully perſuaded the more mathematically and critically the improvements are inveſtigated, the more perfect they will prove to be.

" It was firſt obſerved, that my method did not ſo completely detach the train of wheels from the balance as another ſcapement then referred to. I beg leave to remark, that the train of wheels in mine is prevented from preſſing againſt the locking, by the whole power of the remontoire-ſpring; ſo that the balance has only to remove the ſmall remaining preſſure, which does away that objection, and alſo that of the diſadvantage of detents, as this locking may be compared to a light balance turning on fine pivots, without a pendulum-ſpring; and has only the advantage of banking ſafe at two turns of the balance, and of being firmer, and leſs liable to be out of repair than any locking where ſpring-work is uſed, but likewiſe of unlocking with much leſs power.—It was then obſerved, it required more power to make it go than uſual. Permit me to ſay, it requires no more power than any other remontoire-ſcapement, as the power is applied in the moſt mechanical manner poſſible.—And, laſtly, it was ſaid, that it ſet or required the balance to vibrate an unuſually large arch before the piece would go. This depends on the accuracy of the execution, the proportionate diameter and weight of the balance, the ſtrength of the remontoire-ſpring, and the length of the pallets. If theſe circumſtances are well attended to, it will ſet but little more than the moſt generally detached ſcapements."

A, ſhews the ſcape-wheel, pl. XXIX.

B, the lever-pallet, on an arbor with fine pivots, having at the lower end

C, the remontoire or ſpiral ſpring fixed with a collar and ſtud, as pendulum-ſprings are.

D, the pallet of the verge, having a roller turning in ſmall pivots for the lever-pallet to act againſt.

E, Pallets to diſcharge the locking, with a roller between, as in fig. 10.

F, the arm of the locking-pallet continued at the other end to make it poiſe, having ſtuds and ſcrews to adjuſt and bank the quantity of motion.

a and *b*, the locking-pallets, being portions of circles, faſtened on an arbor turning on fine pivots.

G, the triple fork, at the end of the arm of the locking pallets.

The centre of the lever-pallet in the draft, is in a right line between the centre of the ſcape-wheel and the centre of the verge, though in the model it is not: but may be made ſo or not, as beſt ſuits the calliper, &c.

"The ſcape-wheel A, with the tooth 1, is acting on the lever-pallet B, and has wound up the ſpring C: the verge-pallet D (turning the way repreſented by the arrow) the moment it comes within the reach of the lever pallet, the diſcharging pallet E, taking hold of one prong of the fork, removes the arm F, and relieves the tooth 3 from the convex part of the lock *a*. The wheel goes forward a little, juſt ſufficient to permit the lever-pallet to paſs, while the other end gives the impulſe to the balance: the tooth 4 of the wheel is then locked on the concave ſide of the lock *b*, and the lever-pallet is ſtopped againſt the tooth 5, as in fig. 11. So far the operation of giving the impulſe, in order again to wind the remontoire-ſpring (the other pallet at E, in the return, removing the arm F the contrary direction), relieves the tooth 3 from the lock *b*. The wheel again goes forward, almoſt the whole ſpace, from tooth to tooth, winds the ſpiral ſpring again, and comes into the ſituation of fig. 1, and thus the whole performance is completed. The end of the lower pallet B reſting on the point of the tooth 1, prevents the wheel exerting its full force on the lock *a*, as in fig. 1. The ſame effect is produced by the pallet lying on the tooth 5, by preventing the wheel from preſſing on *b*; and thus the locking becomes the tighteſt poſſible. This ſcapement may be much ſimplified by putting a ſpring with a pallet made in it, as in fig. 12. inſtead of the lever-pallet, and ſpiral-ſpring. The operation will be in other reſpects exactly the ſame, avoiding the friction of the pivots of the lever-pallet. This method I prefer for a piece to be in a ſtate of reſt, as a clock; but the diſadvantage, from the weight of the ſpring in different poſitions, is obvious. The locking may be on any two teeth of the wheel, as may be found moſt convenient."

Many other ingenious ſcapements have been contrived by Harriſon, Hindley, Ellicot, Lepaute, Le Roy, Berthoud, Arnold, Whiethurſt, Earnſhaw, Nicholſon, &c. But deſcriptions of them would extend this article to much too great a length. What is here collected will, we truſt, furniſh ſome inſight into the nature of a few of the moſt approved ſcapements; and thoſe who need further information will do well to conſult ſome of the beſt treatiſes mentioned in the general catalogue given under the word CLOCKWORK.

ARCHIMEDES's SCREW, or the *Waterſnail*, is a machine for raiſing water, which conſiſts either of a pipe wound ſpirally round a cylinder, or of one or more ſpiral excavations formed by means of ſpiral projections from an internal cylinder, covered by an external coating, ſo as to be watertight. This ſcrew is one of the moſt ancient, and at the ſame time ingenious, machines we know, being truly worthy of the name it bears, ſuppoſing Archimedes to be the real inventor. Though ſimple in its general manner of operation, its theory is attended with ſome difficulties which could only be conquered by the modern analyſis: it was firſt ſtated correctly, as far as we have been able to aſcertain, by M. *Pitot*, in the *Mémoires de l'Academie Royale des Sciences*, and afterwards more elaborately by *Euler* in *Nov. Comment. Petropol. tom.* 5. Later attempts by *Langsdorf* in his *Handbuch der Maſchinenlehre*, and ſome other authors, are not to be relied on. That the nature of this curious machine may be the better underſtood, we ſhall firſt ſtate generally its manner of operation; and then preſent a more particular view of the calculus neceſſary to ſhew the work it will really perform, and the force required as a firſt mover.

1. If we conceive that a flexible tube is rolled regularly about a cylinder from one end to another; this tube or canal will be a ſcrew or ſpiral, of which we ſuppoſe the intervals of the ſpires or threads to be equal. The cylinder being placed with its axis in a vertical poſition, if we put in at the upper end of the ſpiral tube a ſmall ball of heavy matter, which may move freely, it is certain that it will follow all the turnings of the ſcrew from the top to the bottom of the cylinder, deſcending always as it would have done had it fallen in a right line along the axis of the cylinder, only it would occupy more time in running through the ſpiral. If the cylinder were placed with its axis horizontally, and we again put the ball into one opening of the canal, it will deſcend, following the direction of the firſt demi-ſpire; but when it arrives at the loweſt point in this portion of the tube it will ſtop. It muſt be remarked that, though its heavineſs has no other tendency than to make it deſcend in the demi-ſpire, the oblique poſition of the tube, with reſpect to the horizon, is the cauſe that the ball, by always deſcending, is always advancing from the extremity of the cylinder whence it commenced its motion, to the other extremity. It is impoſſible that the ball can ever advance more towards the further, or, as we ſhall call it, the *ſecond* extremity of the cylinder, if the

cylinder placed horizontally remains always immoveable; but if, when the ball is arrived at the bottom of the firſt demi-ſpire, we cauſe the cylinder to turn on its axis without changing the poſition of that axis, and in ſuch manner that the loweſt point of the demi-ſpire on which the ball preſſes becomes elevated, then the ball falls neceſſarily from this point upon that which ſucceeds, and which becomes loweſt; and ſince this ſecond point is more advanced towards the ſecond extremity of the cylinder than the former was, therefore by this new deſcent the ball will be advanced towards that extremity, and ſo on throughout, in ſuch a manner that it will at length arrive at the ſecond extremity by always deſcending, the cylinder having its rotatory motion continued. Moreover, the ball, by conſtantly following its tendency to deſcend, has advanced through a right line equal to the axis of the cylinder, and this diſtance is horizontal becauſe the ſides of the cylinder were placed horizontally. But if the cylinder had been placed oblique to the horizon, and we ſuppoſe it to be turned on its axis always in the ſame direction, it is eaſy to ſee that if the firſt quarter of a ſpire actually deſcends, the ball will move from the lower end of the ſpiral tube, and be carried ſolely by gravity to the loweſt point of the firſt demi-ſpire, where, as in the preceding caſe, it will be abandoned by this point as it is elevated, by the rotation, and thrown by its heavineſs upon that which has taken its place: whence, as this ſucceeding point is further advanced towards the ſecond extremity of the cylinder, than that which the ball occupied juſt before, and conſequently more elevated; therefore the ball while following its tendency to deſcend by its heavineſs, will be always more and more elevated by virtue of the rotation of the cylinder. Thus it will, after a certain number of turns, be advanced from one extremity of the tube to the other, or through the whole length of the cylinder; but it will only be raiſed through the vertical height determined by the obliquity of the poſition of the cylinder.

Inſtead of the ball let us now conſider water as entering by the lower extremity of the ſpiral canal, when immerſed in a reſervoir; this water deſcends at firſt in the canal ſolely by its gravity; but the cylinder being turned, the water moves on in the canal to occupy the loweſt place; and thus by the continual rotation is made to advance further and further in the ſpiral, till at length it is raiſed to the upper extremity of the canal where it is expelled. There is, however, an eſſential difference between the water and the ball: for the water, by reaſon of its fluidity, after having deſcended by its heavineſs to the loweſt point of the demi-ſpire, riſes up on the contrary ſide to the original level; on which account more than half one of the ſpires may ſoon-be filled with the fluid. This is an important particular, which, though it need not be regarded in a popular illuſtration, muſt be attended to in the more particular exhibition of the theory to which we now proceed.

2. The moſt ſimple method of tracing a ſcrew or a helix upon a cylinder is well known to be this: take the height or length of a cylinder for one leg of a right-angled triangle, and make the other leg equal to as many times the circumference of the baſe of the cylinder, as the ſcrew is to make convolutions about the cylinder itſelf; then if this triangle be enveloped about the ſurface of the ſolid, the two legs being made, the one to lie parallel to the axis of the cylinder, the other to fold upon the circumference of its baſe, the hypothenuſe will form the contour of the ſcrew. Suppoſe therefore here, that upon the cylinder ABCD (fig. 6. pl. XXIV.) we have rolled the right-angled triangle BDE, and that its hypothenuſe DE traces upon the cylinder the contour of the helix or the ſpires BF, GH, &c. Then if a tube be formed according to the direction of this ſpiral, and a ſmall ball put into it, if the cylinder were placed upright, the ball would roll to the bottom with the ſame velocity and the ſame force, as it would have deſcended upon the plane DE, if BE were horizontal and BD vertical. But if the cylinder be inclined until it makes with the vertical CL an angle ACL equal to the angle BED, or the angle which the threads of the ſcrew make conſtantly with the baſe of the cylinder, in that caſe DE will be parallel to the horizon; and whether the ſpires be few or many, they will all be parallel to the horizon: ſo that there being nothing to occaſion the ball P to move toward either G or H, it will remain immoveable, ſuppoſing the cylinder to be at reſt: but if the cylinder be turned on its axis in one direction, the ball (abſtracting from friction), will move the contrary way, in conformity with the firſt law of motion.

3. The inclination ACL = BED which we have juſt aſſigned, is the leaſt we can give, ſo that the ball ſhall not deſcend of itſelf: but if we augment this inclination, or, make the angle LAC ſmaller, then by turning the cylinder in the direction CMD, the ball will always have a deſcent on the ſide towards H, and will mount, ſo to ſpeak, by deſcending. The reaſon is very ſimple: *the plane which carries it makes it riſe more in conſequence of the rotatory motion, than it deſcends by virtue of the force of gravity.*

4. There are ſeveral methods of determining the ratio of the weight of the ball P to the force F, neceſſary to make it riſe by turning the ſcrew. The following is perhaps the moſt ſimple; the force or power is to the weight elevated, as the vertical

ſpace paſſed over by the weight, is to the ſpace paſſed through by the power in moving it. Here the vertical ſpace is CL, and if the moving force act at the circumference of the cylinder, the ſpace paſſed over by that force will be equal to as many times the circumference of the cylinder's baſe, as there are convolutions of the helix: thus we ſhall have BE : CL :: P : F.

Example. Let the diameter AB of the cylinder be 14 inches, the vertical altitude CL = 12 feet or 144 inches, and 12 the convolutions of the ſpiral, the cylinder being ſo placed that the angle LAC is leſs than BED; the weight to be raiſed being a 48 lb. ball. Then the circumference of the cylinder will be nearly 44 inches, and the 12 turns equal to 12 × 44 = 528 = BE. Hence we have 528 : 144 :: P : F :: 48 : $13\frac{1}{3}$ lbs. the meaſure of the requiſite force at the ſurface of the cylinder. If the moving force deſcribe a circle whoſe diameter is 3 times that of the cylinder, or act at a winch, whoſe diſtance from the axis of motion is 21 inches, that force will then be reduced to $\frac{1}{3}$ of $13\frac{1}{3}$ or $4\frac{4}{9}$ lbs. which is leſs than $\frac{1}{10}$ of the weight of the ball. The friction upon the pivots, &c. is not here conſidered.

Thus it appears that Archimedes's ſcrew may be uſed for other purpoſes than raiſing of water. It might be adapted with advantage in raiſing cannon balls from a ſhip to a wharf: and with the addition of a bevel-wheel or two and their pinions, might be worked either by men or horſes.

5. The helix folded about a cylinder is a curve ſimilar in all its parts; that is, all the demi-ſpires, as AIC, CR, RS, are ſimilar and equal; it is alſo the ſame of the thirds, the fourths, &c. of the ſpires, and generally of all the equal portions of the curve. But when the cylinder is inclined, if we refer all the points of a demi-ſpire, ſuch as AIC, by perpendiculars, to the horizontal ſection of the cylinder (which ſection is elliptical, though repreſented in fig. 7. pl. XXIV. by a right line AD to prevent confuſion in the diagram), we ſhall find that this demi-ſpire has, with regard to the horizontal plane AD, a higheſt point E, a loweſt point E′, and a mean point I. In order to become acquainted with the effect of the ſcrew in raiſing water, it is important to determine theſe three points.

6. The mean point I is a point of inflection very eaſy to determine. To this end put the diameter AB = $2r$, the half-circumference AMB = c, the abſciſſa AP = x, the indeterminate arc AM = s, the ordinate ME of the ſpiral = y, and the height BC of a demi-ſpire = b. Hence, ſince we may conſider the demi-ſpire AIC as having been formed by the hypothenuſe of a right-angled triangle, one leg of which is equal to the half-circumference AMB, and the other equal to the line BC, we have this proportion, AMB : BC :: AM : ME, or c : b

:: $s : y$; whence, $s = \frac{cy}{h}$, the fluxion of which is $\dot{s} = \frac{c\dot{y}}{h}$. But by the nature of the circle $\dot{s} = \frac{r\dot{x}}{\sqrt{(2rx - x^2)}}$; ſo that $\frac{r\dot{x}}{\sqrt{(2rx - x^2)}} = \frac{c\dot{y}}{h}$. Therefore, following the uſual method for points of inflexion, by taking the ſecond fluxions and ſuppoſing $\dot{x}$ conſtant, we have $\frac{hrx\dot{x}^2 - hr^2\dot{x}^2}{c\sqrt{(2rx - x^2)}} = \ddot{y} = 0$, which gives $x = r$, and indicates that the point of inflexion I is in the middle of the demi-ſpire AIC.

7. To find the higheſt and loweſt points E, E′, in addition to the characters before uſed, put BD $= a$, and AD $= f$: we have from the foregoing article $\frac{hs}{c} = y$, and the ſimilar triangles ABD, APF, give AB : BD :: AP : PF, or $2r : a :: x : \frac{ax}{2r}$ = PF. Therefore EF = PE − PF $= \frac{hs}{c} - \frac{ax}{2r}$; for ſince we conſider PM as perpendicular to PE, it follows that ME and PE will be equal, and conſequently PE $= \frac{hs}{c}$. The ſimilar triangles ABD, EFG, give AD : AB :: EF : EG, or, $f : 2r :: \frac{hs}{c} - \frac{ax}{2r} : \frac{2hrs}{cf} - \frac{ax}{f}$ = EG. This value of EG ought to be a *maximum*; its fluxion, therefore, that is, $\frac{2hr\dot{s}}{cf} - \frac{a\dot{x}}{f} = 0$. But from the nature of the circle we have $\dot{s} = \frac{r\dot{x}}{\sqrt{(2rx - x^2)}}$. Subſtituting for $\dot{s}$ in the preceding equation this value of it, and reducing, we ſoon find $x = r \pm \frac{r}{ac}\sqrt{a^2c^2 - 4h^2r^2}$. Of theſe two values of x, the lower determines the value AP correſponding to the higheſt point E; the upper ſhews the value AP′ correſponding to the loweſt point E′.

8. Through the higheſt point E having drawn the horizontal plane EO, this plane will cut the demi-ſpire COS in the point O (fig. 8. pl. XXIV.), thus determining the arc ECO which carries water, or as it is ſometimes called the *hydrophorous arc*; for all the points of this arc being below the points E, O, and theſe

two points being in the level of the ſurface, the water will be in equilibrio in that arc. To find the magnitude, and of conſequence the quantity of water carried by an hydrophorous arc, the diameter of the tube which forms the ſcrew being given, it is evident that we have only now to determine the point O or extremity of the arc ECO, the other extremity having been found by the preceding article. In order to this, denote AB, BD, by the ſame letters as before; the variable abſciſſa BQ by z, and its arc BN by s: the line EF (found as in art. 7.), or its equal OR put $= e$. Then the ſimilar triangles ABD, AQR, give AB : BD :: AQ : QR, or $2r : a :: 2r - z : \frac{2ar - az}{2r} = \text{QR}$: therefore $\text{QO} = \frac{2ar - az}{2r} + e$. Now, by the property of the ſcrew, we have AMB : BC :: AMBN : NO, or $c : h :: c + s : \frac{hc + hs}{c} = \text{NO}$. But QO and NO being two lines perpendicular to the baſe of the cylinder, and both of them terminating in the plane of the ellipſe, or of the cylindric ſection EO, it follows that QO = NO; that is, from what has gone before, $\frac{2ar - az}{2r} + e = \frac{hc + hs}{c}$, or $\frac{az}{2r} + \frac{hs}{c} + h - a - e = 0$. As the reſolution of this equation depends upon the rectification of the arc s, we can only ſubſtitute the value of s in terms of z, by an infinite ſeries formed of z and its powers; where the reſulting equation becoming more and more complex and embarraſſing, as a greater number of terms of the ſeries is taken, we ſhould, by purſuing it, be involved in a very long and tireſome operation: to avoid this we ſhall have recourſe to the following table calculated by M. Pitot.

This table contains values of the arcs BN $= s$, correſponding to thoſe of BQ $= z$, given in parts of the diameter AB $= 2r$, divided in 200 parts. This granted, having found by the preceding article the value of e, we reduce $h - a - e$ to one number only, which let be repreſented by n: then have we $\frac{az}{2r} + \frac{hs}{c} = n$. Laſtly, we take in the table different values of z and of the correſponding arc, till we have diſcovered that which renders $\frac{az}{2r} + \frac{hs}{c}$ equal to the number n, or nearly ſo.

To find the length of the hydrophorous arc ECO, having determined the arcs AM and BN, it is proper to obſerve that, by the formation of the ſcrew (art. 2.), the length of one of the demi-ſpires AEC is equal to the hypothenuſe of a right-angled triangle, of which AMB $= c$, and BC $= b$ are the legs: thus the demiſpire AEC $= \sqrt{cc + bb}$. If now we put m for the known arc MBN, we may take this analogy, viz. AMB : AEC : : MBN : ECO, or $c : \sqrt{c^2 + b^2} : : m : \frac{m}{c}\sqrt{c^2 + b^2} =$ ECO; and thus obtain the value of the arc which carries the water, or of the hydrophorous arc ſought.

Table of arcs correſponding to parts of radius divided into 100 equal parts.

Part of Radius.	Arcs in parts of radius.	Arcs in deg. and min.	Parts of radius.	Arcs in parts of radius	Arcs in deg. and min.
1	14·14	8° 6′	18	60·88	34° 54′
2	20·	11 28	19	62·62	35 54
3	24·54	14 4	20	64·31	36 52
4	28·35	16 15	21	65·94	37 48
5	31·72	18 11	22	67·57	38 44
6	34·77	19 56	23	69·17	39 39
7	37·59	21 33	24	70·74	40 33
8	40·24	23 4	25	72·73	41 25
9	42·71	24 29	26	73·73	42 16
10	45·06	25 50	27	75·21	43 7
11	47·30	27 7	28	76·66	43 57
12	49·45	28 21	29	78·16	44 46
13	51·62	29 32	30	79·52	45 35
14	53·52	30 41	31	80·90	46 22
15	55·44	31 47	32	82·25	47 9
16	57·30	32 51	33	83·62	47 56
17	59·16	33 55			

9. *Example of the calculation of an hydrophorous arc.* For an example of this kind of calculation for the length of the hydrophorus arc ECO, let us take the diameter AB $= 2r$ of 200 parts, the height BC $= h = 80$ of the ſame parts, BD $= a = 100$ parts; then the ſemi-circumference AMB will be nearly $= 314$ of thoſe parts. Subſtituting theſe values in the expreſſion $x = r - \frac{r}{ac}\sqrt{a^2c^2 - 4b^2r^2}$ (art. 7.), there reſults AP $= x = 13·45$ of the ſame parts; and by means of the table juſt given, the arc AM $= s$, is found $= 53·3$. Subſtituting theſe values of x and s in the equation $\frac{hs}{c} - \frac{ax}{an} = e$, we find the value, e, of EF or RO $= 6·86$.

To have at the ſame time the value of BQ = z, and of the arc BN which we now call s; theſe values of a, b, c, $2r$ and e muſt be ſubſtituted in the equation $\frac{az}{2r} + \frac{ks}{c} = a - b + e$, ſo as to have $z + \frac{805}{157} = 53{\cdot}72$. By means of the preceding table it is ſoon found that BQ = $z = 21$, and BN = $s = 66$, very nearly.

Then to find the arc MBN, which we have called m, we have the whole arc AMBN $= 314 + 66 = 380$, from which deducting the arc AM $= 53{\cdot}3$, there remains MBN $= m = 326{\cdot}7$. The length of the demi-ſpire AEC $= \sqrt{c^2 + b^2} = 324{\cdot}03$: and finally $\frac{m}{c}\sqrt{c^2 + b^2} = 337{\cdot}13$ the length of the hydrophorous arc ECO.

10. *The diameter of the cylinder of the ſcrew being given with that of the tube which forms the ſpiral, and the given length of the ſcrew, to find the quantity of water carried by the hydrophorous arcs, and the height to which the water is elevated, the inclination of the ſpiral being as before.*

Let the diameter AB of the ſcrew be 1 foot, that of the ſpiral tube in which the water is raiſed 3 inches, and the length of the ſcrew 30 feet. This granted, to have the length in feet and inches of an hydrophorous arc, ſay, as the 200 parts of the diameter of the table : 1 foot or 12 inches :: 337·13 before found : 20·2278 inches, the real length of the hydrophorous arc. Every ſuch arc then carries a cylinder of water 3 inches diameter and 20·2278 inches long. Let us next enquire how many ſuch arcs there will be in the whole length of the ſcrew, or 30 feet. It is evident, in the firſt place, that every turn or convolution of the helix on the arbor of the ſcrew carries one hydrophorous arc: to find, therefore, the number of turns, it muſt be obſerved that the height BC of one of the demi-ſpires is in our example 80 parts, or the height AS of an entire ſpire 160 parts; the diameter AB of the baſe, which is 1 foot, being 200 of thoſe parts: hence 200 : 12 :: 160 : 9·6 inches, the height of one ſpire. Dividing the inches in 30 feet by 9·6, the quotient gives more than 37 for the number of ſpires; conſequently there will be 37 hydrophorous arcs. The quantity of water in all theſe hydrophorous arcs is equal to the quantity in a cylinder the diameter of whoſe baſe is 3 inches, and height $= 20{\cdot}2278 \times 37 = 748{\cdot}4286$ inches, or nearly $62\frac{1}{3}$ feet. Such a cylinder of water is eaſily found to weigh 191·313 lbs. avoirdupois.

We have now to determine the vertical height to which the ſcrew we have taken for an example will elevate the water: and this may be accompliſhed very eaſily; for, the triangles ADB, BYZ, being ſimilar, we have AD : AB :: BY : YZ = 26·833 feet. Finally, under this head, to find the angle which the arbor or axle of this ſcrew makes with the horizon, ſay, as BD : BA :: rad. : tan. ADB = tan. YBZ the angle ſought: thus the angle YBZ is found = $63^\circ 26'$.

11. *Computation of the force requiſite to turn the ſcrew.*—In the example we have talen, the weight of the water contained in the 37 hydrophorous arcs being 191·313 lbs. to find the force neceſſary to be applied at the circumference of the cylinder, we muſt ſay, according to the rule in art. 4. as 37 times the circumference of the cylinder's baſe (= 1395·714 inches) is to the vertical height through which the water is elevated (= 26f. 10 i. = 322 inches), ſo is the weight of water (= 191·313 lbs.) to the weight 44·14 lbs. equivalent to the force which muſt be applied to the circumference of the ſcrew to keep it in motion when once it has begun to turn. But if this force or power, inſtead of being applied at the circumference of the ſcrew, acts by a handle and winch at the diſtance of 10 inches from the axis of the cylinder, the requiſite force will only be $\frac{6}{10}$ or $\frac{3}{5}$ of the former; it will, therefore, be 26·48 lbs.

12. *Computation of the quantity of water which the ſcrew will raiſe in a given time.*—To find the quantity of water raiſed by the ſcrew propoſed as our example, we muſt know the velocity with which the aſſigned force carries round the handle. Suppoſe, for inſtance, the handle, and conſequently the ſcrew, makes one rotation in 5 ſeconds, it is very manifeſt the ſcrew will then expel the quantity of water contained in 1 hydrophorous arc in 5 ſeconds; and in 37 times 5 ſeconds, that is 185 ſeconds or 3^m 5^s, it will raiſe a quantity weighing 191·313 lbs. To find the quantity raiſed in an hour, ſay, as 185 : 3600 (ſeconds in an hour) :: 191·313 : 3719 lbs. nearly. Or, if the quantity be calculated in ale gallons, it will be found equal to 364·62. If the velocity with which the handle is moved be tripled, which it may be, without rendering the work too fatiguing, the quantity raiſed will be tripled, and nearly 1094 gallons will be raiſed 26 feet 10 inches, in an hour. This coincides very nearly with Deſaguliers's eſtimate of the water which a man can raiſe by almoſt any hydraulic engine.

13. Having dwelt thus long upon the theory of Archimedes's ſcrew, but little remains to complete our obſervations. It is obvious from what has been remarked, that this ſcrew can never raiſe water when the angle which the central line of the ſpiral makes with the baſe of the cylinder is larger than the angle included between the baſe of the cylinder and the horizon; that

is, it is always neceſſary that BAZ ſhould be equal to, if not greater than, BED (fig. 6. pl. XXIV). In practice, indeed, it is adviſeable that CAL be between 40° and 60°, and BAZ – BED between 10° and 20°. The mean of both theſe is moſt to be recommended.

Sometimes Archimedes's ſcrew, inſtead of being worked by men at a winch, is turned by means of float-boards fixed about the circumference of its lower end, upon which a ſtream of water acts: if the water have a moderate fall, it will have ſufficient efficacy to turn two ſcrews, one above another; the top of the lower ſcrew and the bottom of the upper ſcrew may act the one upon the other, by means of a wheel upon each, with an equal number of teeth taking into each other: in this caſe the upper ſcrew will turn in a contrary direction from the other, and conſequently the ſpiral tube muſt be wound about the cylinder in an oppoſite direction. A ſolid wheel, or a light wheel with a heavy rim, turning upon the middle of the ſcrew as an axis, will operate like a fly, and in ſome caſes be very uſeful.

In the preceding inveſtigations no notice has been taken of the effects of the air included in the ſpiral: yet if the ſpiral had been folded upon a cone inſtead of a cylinder, or if it had been formed of a flexible tube of varying diameter, theſe effects would have been important: ſome of them are conſidered in our account of the ſpiral pump. See *Hydraulic Machines*, No. 10.

SHOEMAKERS' IMPLEMENT, *to enable them to work in a ſtanding poſture.* This inſtrument has been lately contrived by Mr. Thomas Holden of Fettleworth, Suſſex; and its inventor has been rewarded with fifteen guineas by the Society of Arts. It reſembles a ſtand, ſuch as is uſed for reading-deſks; at the top of which is a ſmall block of wood, excavated ſo as to form a proper bed for the laſt, and the moulds or inſtruments uſed in making boots, which are kept firm upon it, by a ſtirrup or endleſs ſtrap. The hollow block is joined into another piece (which connects it to the ſtand), ſo as to admit of a vertical motion; and it is retained, at any angle, in this motion, by a circular catch, with notches formed in its ſide, to faſten it on an iron catch projecting from the lower piece. This lower piece is ſhaped into a ſmall cylinder beneath, which entering into a hole formed for it in the top of the pillar of the ſtand, permits the hollow block to be moved round about, without ſtirring the ſtand; ſo that, by the combination of theſe two motions, it may be placed in any poſition. Behind the hollow block, and on a level with it, an horizontal piece of board is ſupported by a ſmall pillar, riſing from one of the feet of the ſtand, and ſecured firmly by a brace to the ſtand itſelf; this board ſupports the tools and implements wanted, ready at hand for the workman's uſe.

The deſign of this invention is to obviate the neceſſity of uſing that very unwholeſome poſture in which ſhoemakers are accuſtomed to work; which compreſſes the lungs and bowels in ſuch a manner, as to occaſion conſumption, inflammation of the bowels, and a variety of other frightful complaints.

The efficacy of the alteration of poſture permitted by this inſtrument, which enables the workman to ſtand at his work, is very well proved in the caſe of the inventor of it; who has produced a medical certificate, that he was, for many years, ſo afflicted with bowel complaints and piles, that he was under the neceſſity of leaving off his trade entirely, if he could not contrive to work ſtanding; and that, ſince he has made uſe of this implement, his complaints are entirely removed, and he is ſo improved in fleſh and countenance, that he "looks not like the ſame man;" and, for ſome years, has had no occaſion for medicine. He has made many hundred pair of ſhoes on this ſtand, and recommends alſo its uſe, as "the quickeſt way of cloſing all the thread work."

This implement might be made ſtill more ſimple, by leaving out the part uſed to give the hollow block a circular motion, which does not appear always neceſſary, from the facility which the workman has, when ſtanding at it, to place himſelf inſtantly at any ſide of the work he pleaſes; it would, as appears to us, be full as little, if not leſs, trouble to him to let the inſtrument remain unmoved, and turn himſelf round inſtead of it, as to ſtand ſtill while he turned it about: though a ſmall quantity of light confined to one direction may in ſome caſes render the increaſed apparatus neceſſary.

A wooden vice of a proper height, fixed to a ſtake, and ſecured even by a wedge, if a ſcrew ſhould be deemed expenſive, would alſo hold a laſt in any poſition required for the workman.

Theſe additional obſervations are given, becauſe any contrivance which will enable ſhoemakers to work in poſtures leſs injurious to their health muſt be conſidered as important and valuable: and whatever may ſuggeſt to the workman cheap inſtruments for this purpoſe, eaſily conſtructed, and pleaſant in the practice, cannot but be beneficial to the public.

SIPHON. See CRANE.

SPIRAL-PUMP, *at Zurich*. See HYDRAULIC *Engines*. No. 10.

STEAM-ENGINE, an engine originally contrived for raiſing water by means of the expanſive force of the ſteam or vapour produced from water or other liquids in a ſtate of ebullition. This has been often called the *Fire-engine*, becauſe of the fire uſed in boiling the liquid; but the latter term has, of late, been properly confined to machines for extinguiſhing fires. The ſteam-engine is juſtly deemed one of the moſt curious, important, and ſerviceable mechanical inventions, not only of modern, but of any, times; particularly when it is conſidered with regard to ſome of its late improvements, which render it applicable to all kinds of mill-work, to planing, ſawing, boring, and rolling machines, and indeed to almoſt every purpoſe that requires a powerful firſt-mover, whoſe energy may be modified at the pleaſure of the mechaniſt.

The principles and manner of operation of the ſteam-engines of Savery, Newcomen and Cawley, and of Watt, may be underſtood from the following brief explanations and remarks, which are meant as preparatory to the more detailed accounts of ſeveral engines with which we have been favoured.

1. Let there be a ſucking pipe with a valve opening upwards at the top, communicating with a cloſe veſſel of water, not more than thirty-three feet above the level of the reſervoir, and the ſteam of boiling water be thrown on the ſurface of the water in the veſſel, it will force it to a height as much greater than thirty-three feet as the elaſtic force of the ſteam is greater than that of air; and if the ſteam be condenſed by the injection of cold water, and a vacuum thus formed, the veſſel will be filled from the reſervoir by the preſſure of the atmoſphere; and the ſteam being admitted as before, this water will alſo be forced up; and ſo on ſucceſſively.

Such is the principle of the firſt ſteam-engine, ſaid by the Engliſh to be invented by the *marquis of Worceſter;* while the French aſcribe it to *Papin:* though we believe the fact is that *Brancas*, an Italian, applied the force of ſteam ejected from a large œlopile as an impelling power for a ſtamping-engine ſo early as 1629. The hint ſo obſcurely exhibited in the marquis of Worceſter's Century of Inventions was carried into effect by captain Savery.

2. If the ſteam be admitted into the bottom of a hollow cylinder, to which a ſolid piſton is adapted, the piſton will be forced upwards by the difference between the elaſtic forces of ſteam and common air; and the ſteam being then condenſed, the piſton will deſcend by the preſſure of the atmoſphere, and ſo on ſucceſſively. This is the principle of the ſteam-engine firſt contrived by Meſſieurs *Newcomen* and *Cawley*, of Dartmouth. This is ſometimes called the atmoſpherical engine, and is commonly a forcing-pump, having its rod fixed to one end of a lever, which is worked by the weight of the atmoſphere upon a piſton at the other end, a temporary vacuum being made below it by ſuddenly condenſing the ſteam, that had been admitted

into the cylinder in which this piſton works, by a jet of cold water thrown into it. A partial vacuum being thus made, the weight of the atmoſphere preſſes down the piſton, and raiſes the other end of the ſtraight lever, together with the water, from the well. Then immediately a hole is uncovered in the bottom of the cylinder, by which a freſh quantity of hot ſteam ruſhes in from a boiler of water below it, which proving a counterbalance for the atmoſphere above the piſton, the weight of the pump-rods, at the other end of the lever, carries that end down, and raiſes the piſton of the ſteam-cylinder. The ſteam hole is then immediately ſhut, and a cock opened for injecting the cold water into the cylinder of ſteam, which condenſes it to water again, and thus making a vacuum below the piſton, the atmoſphere again preſſes it down and raiſes the pump-rods, as before; and ſo on continually.

3. The great features of improvement made by Mr. *Watt* upon the engine of Newcomen and Cawley are, as Mr. Nicholſon remarks, firſt, that the elaſticity of the ſteam itſelf is uſed as the active power in this engine; and ſecondly, that beſides various other judicious arrangements for the economy of heat, he condenſes the ſteam, not in the cylinder, but in a ſeparate veſſel.

In the cylinder or ſyringe, concerning which we have ſpoken, in mentioning the engine of Newcomen, let us ſuppoſe the upper part to be cloſed, and the piſton-rod to ſlide air-tight through a collar of leathers. In this ſituation, it is evident that the piſton might be depreſſed by throwing the ſteam upon its upper ſurface, through an aperture at the ſuperior end of the cylinder. But if we ſuppoſe the external air to have acceſs to the lower ſurface of the piſton, we ſhall find that ſteam no ſtronger in its elaſticity than to equal the weight of the atmoſphere would not move the piſton at all; and conſequently that this new engine would require much denſer ſteam, and conſume much more fuel than the old engine. The remedy for this evil is to maintain a conſtant vacuum beneath the piſton. If ſuch a vacuum were originally produced by ſteam, it is certain that its permanency could not be depended on, unleſs the engine contained a proviſion for conſtantly keeping it up. Mr. Watt's contrivance in his ſimpleſt engine is as follows: The ſteam is conveyed from the boiler to the upper part of the cylinder through a pipe, which alſo communicates occaſionally with the lower part, and beyond that ſpace with a veſſel immerſed in a trough of water; in which veſſel the condenſation is performed by an injected ſtream of cold water. This water is drawn off, not by an eduction-pipe but by a pump, of which the ſtroke is ſufficiently capacious to leave room for the elaſtic fluid, ſeparated during the injection, to follow and be carried out with the injection water. Suppoſe now the piſton to be at its greateſt elevation, and the communication from the boiler to the upper as well as to the lower parts of the cylinder to be opened. The ſteam will then paſs into the whole internal part of the engine, and will drive the air downwards into the condenſer, and thence through the valves of the air-pump. In this ſituation, if the communication from the boiler to the lower part of the cylinder be ſtopped, and an injection be made into the condenſer, a vacuum will be produced in that veſſel, and the ſteam contained in the lower part of the cylinder and communication pipe will expand itſelf with wonderful rapidity towards the condenſer, ſo that in a period of time too minute to be appreciated the whole of the ſteam beneath the piſton will be practically condenſed. The ſteam which continues to act above the piſton will immediately depreſs it into the vacuum beneath; at the ſame time that by connection with the external apparatus the piſton of the air-pump alſo deſcends in its barrel. When the ſtroke is nearly completed downwards, the requiſite part of the apparatus ſhuts the communication with the boiler, opens that between the upper and lower parts of the cylinder and condenſing veſſel, and turns the injection-cock. At this very inſtant the piſton loſes its tendency to deſcend, becauſe the ſteam preſſes equally on both ſurfaces, and continues its equality of preſſure while the condenſation is performed. It therefore riſes; the injection is ſtopped; and the air-pump making its ſtroke, ſuffers the injection water and a conſiderable part of the elaſtic fluid to paſs through its lower valve. The vacuum is thus kept up through the whole internal capacity of the engine. As ſoon as the piſton has reached the upper part of the cylinder, the communication to the under part of the cylinder is ſtopped, and that with the boiler opened, as before; the conſequence of which is, that the piſton again deſcends; and in this manner the alternations repeatedly take place.

The principal augmentation of power in this engine, compared with that of Newcomen, ariſes from the cylinder not being cooled by the injection water, from its being practicable to uſe ſteam, which is more powerful than the preſſure of the atmoſphere, and from the employing of this ſteam both to elevate and to depreſs the piſton. In general, theſe engines are worked by ſteam, which would ſupport a column of four or five inches of mercury beſides the preſſure of the atmoſphere, and ſometimes more; for Mr. Nicholſon ſays, he has ſometimes ſeen the gage as high as eight inches. Mr. Watt has made ſeveral ſucceſſive modifications and additions to the engine juſt deſcribed, ſome of which will be further ſpoken of in the courſe of this article.

4. It has been cuſtomary, when treating of ſteam-engines, to preſent ſeveral theorems for the computation of their power and effects. But as all which has hitherto been advanced on theſe points ſeems to us very vague and unſatisfactory, we ſhall not delude the ſtudent with an appearance of mathematical accuracy, when it is ſo far from being attained. It is obvious enough that the abſolute power of a ſteam-engine is in the compound ratio of the area of the piſton, the preſſure upon each inch of it, the length of the ſtroke, and the number of ſtrokes in any aſſigned time: but the preſſure upon any portion of the piſton can only be aſcertained by experiment and obſervation, and that with difficulty, becauſe of our uncertain methods of eſtimating friction and other ſpecies of reſiſtance; while judicious obſervations would with much leſs labour determine the work actually performed, either when the ſteam-engine works pumps, or gives motion to any kind of mills. The quantity of water raiſed by pumps in a given time may ſoon be eſtimated; and when the alternating motion of the ſteam-piſton is converted into a rotatory one, the real effect the engine is capable of producing may be aſcertained by obſerving the velocity with which a given weight is raiſed when ſuſpended from the axle to which the rotation is firſt given.

The uſual method of eſtimating the effects of engines by what are called "horſe powers" muſt inevitably be very fallacious, unleſs all engineers could agree as to the quantity of work which they would arbitrarily aſſign to *one* horſe, and in that caſe the term would manifeſtly be nugatory. It may alſo be obſerved, that in determining the comparative value of different ſteam-engines, it is not ſufficient to compare the quantities of work each will perform in equal times; for the expence of erection, the probability of repairs being more or leſs frequent on account of the complexneſs or ſimplicity of conſtruction, and the quantities of fuel conſumed by each, muſt likewiſe be taken into the account.

Theſe particulars might eaſily be enlarged upon: but it will probably be more beneficial to the reader if we now ſuſpend our own remarks, in order to preſent them with the communications with which we have been favoured: theſe are, one from Mr. *J. C. Hornblower*, engineer, containing a ſketch of the later hiſtory, with deſcriptions of the principal engines; another from Mr. *J. Farey*, jun. of Crown-ſtreet, Weſtminſter (a young gentleman of remarkable mechanical attainments), being an account of an engine erected in 1802 by Meſſrs. Murray and Wood, of Leeds.

I. It is remarkable that we have nothing handed to us on this ſubject that is worthy of our reception, notwithſtanding the number of our Cyclopedias and Encyclopedias, unleſs it be what is publiſhed in the Minor's Friend by Mr. Thomas Savery, and afterwards in Harris's Lexicon Technicum; and theſe, but eſpecially the former, with all the frankneſs and faithfulneſs of undiſguiſed fact, have put to the bluſh thoſe pompous conceits and abſurdities that have either wilfully or ignorantly been trumped up to allure the undiſcerning multitude, or to prattle the praiſe of the ingenious inventors.

It will be unneceſſary to go over the ground already beaten ſo bare by Deſaguliers and his followers, though there are ſome things which do deſerve notice. The firſt thing is as to the degree of credit that is to be attached to the doctor's account of what paſſed in the ſucceſſive improvements of what was then, and for a long while after, called the *fire-engine.* No doubt there were many accidental diſcoveries in the improvement of this as well as other pieces of machinery; and it cannot be a reflection on the underſtanding of any man when we are told that it is in this way that many, if not moſt, of our acquiſitions in chemiſtry and experimental philoſophy are brought to light; forcing themſelves, as it were, upon us, challenging our judgment and humbling our pride. But to proceed.—The doctor has met with an unhappy inſtance of this ſort when he tells us that the way of *leathering* the piſton was found out by accident, which he relates thus: "Having ſcrewed a large broad piece of leather to the piſton, which turned up the ſides of the cylinder two or three inches, in working it wore through and cut that piece from the other, which falling flat on the piſton wrought with its edge to the cylinder, and, having been in *a long time*, was worn very narrow: which being taken out, they had the happy diſcovery whereby they found that a bridle rein, or even a ſoft thick piece of rope or match going round, would make the piſton air and water tight." We need not ſay any thing to the practical engineer about *leathering* a *ſteam-piſton*, nor is it neceſſary to comment on the doctor's acquaintance with ſteam and leather in contact. The next thing is the reſult of an experiment made by Mr. Beighton to determine the bulk of ſuch ſteam uſually applied to working a fire-engine, in compariſon with the bulk of water which produces it, which he makes out to be as 13338 to 1; and our bookmakers, in their expanding regard to the intereſts of the riſing generation, have quoted this experiment one edition after another, till it is doubtful whether it will be poſſible to undeceive them. Nay, the editor of the Encyclopedia Britannica has improved upon this eſtimate, and calls it 14000 to 1.

But let us ſee what it is according to the data we can collect from Mr. Beighton's ſtatement. Griff cylinder held 113 gallons, wrought 16 ſtrokes per minute, and took 5 pints of water to ſupply ſteam for that number of ſtrokes, each pint containing 38.2 inches. Now 38.2 × 5 = 191 inches in 5 pints; $\frac{191}{16} = 12$, the number of inches required to make ſteam for 1 ſtroke. Then 113×282=the inches contained in the cylinder=31866, and this divided by 12 gives 2655½, the number of times the water is rarefied, or as 2655½ to 1. But this being an atmoſpherical engine expoſed to all the defects which we have been ſo anxious to improve, muſt have given a very different reſult: this being even more than what may be obſerved in ſome of the moſt improved engines of the preſent time. In ſhort, little dependence muſt be placed on the relation of experiments at ſo remote a period, or even on the experiments themſelves, being in general very looſely conducted. But it ſeems rather ſingular that at the firſt dawn of the ſteam-engine its principles and mode of operation ſhould be related with ſo much more accuracy than what ſucceeded it, or even at any period of improvement is to be found any where in print, at leaſt in this country.

However, we may ceaſe our recurrence to theſe former times, which, though they afforded examples of indefatigable zeal and ardour in the purſuit of a prime object, yet we perceive little ſketch of thought, little diſplay of genius, and a fond concluſion that when one of their favourite deſiderata had been accompliſhed, there remained nothing more of much conſequence even to wiſh for. Friction and inertia were become the moſt important objects to be done away; except that ſome different modes of condenſation had been tried, but with little effect. The principal of them were to keep the jet from applying itſelf to the ſides of the cylinder: for this purpoſe a plate of iron was placed horizontally over the aperture of the injection-pipe, ſo as to prevent the water from ſtriking the bottom of the piſton, and being thereby diſperſed over the lower part of the cylinder: but it was found that it would not produce ſo prompt a condenſation as the general mode. Another mode was tried alſo, which was to form the nether ſide of the piſton into a ſort of inverted cup, nearly the whole area of the piſton, and the jet was thrown up into it. This produced a remarkable change in the temperature of the cylinder, and preſerved all the advantages of the former mode of injection: but no ſucceſs was obtained in point of power, for the vacuum was as incomplete as before; occaſioned by the ſides of the cylinder being conſtantly laved by the water on the piſton, and the temperature of the cylinder being raiſed ſo much above what it was before. In the common method of injection there was an inſtantaneous generation of vapour from the ſides of the cylinder, which could not fail to vitiate the vacuum; added to that, the water in the piſton wherever it was a tight one (which was ſeldom the caſe) grew hot, and the vapour carried off a deal of heat; and no attempts were made to prevent theſe unexpected effects. Many projects were ſuggeſted for the improvement of boilers, ſome of which ſucceeded, and are ſtill in uſe: but the great obſtacle was reſerved to be overcome by Mr. Watt.

It is neceſſary here to obſerve, that hitherto the mode of boring cylinders was the moſt vile that can be imagined. The way uſually was, at ſome of our firſt founderies, to put the cylinder on a carriage, inſert the cutter block, ſet the mill a-going, hang a cloth at the open end to keep in the duſt, and let it bore away, which it would be doing on a large cylinder for three weeks, or a month: and if it was tolerably ſmooth, it was ſaid to be well done. But this was not all: in thoſe engines which were dependent on the water drawn from the mine for the condenſation of the ſteam, the ſides of the cylinder were corroded in a few months in ſuch a manner that no kind of packing could keep the piſton tight; and as theſe inconveniences increaſed like a ſpreading ulcer, it became neceſſary to ram the packing ſo hard, as in many caſes to ſuſtain the whole preſſure of the atmoſphere without making one ſtroke: all the while a cock of at leaſt a round inch water-way from a ciſtern 12 feet high was neceſſary to ſupply the leaking of the piſton. This was not the caſe in collieries, or any-where beſide thoſe mines the water of which contained the vitriolic acid; but ſo great was that at ſome mines, that wherever the water fell on the working gear, or any other part conſtructed of iron, it had the appearance of being fabricated from copper intirely.

It was in this ſtate of things that Mr. Watt brought forth his improvement, when he engaged to grant licences to uſe his engines for the conſideration of receiving one third part of the profits ariſing from the abatement of coal uſually conſumed in the miſerable ſtate of the old engines; and the ſavings turned out to be very advantageous, but more to him than to the proprietors: for there opened other channels of expenditure on the new engines which were not taken into the account, and which were never heard of in the account of the old ones. Firſt, in the expence of erection, which was generally cent per cent above the coſt of the old engines; and ſecondly, the monthly expence for maintainance; for as there was a neceſſary degree of accuracy to be obſerved in getting up the various apparatus belonging to them, ſo it was neceſſary that this accuracy ſhould be preſerved: this made a difference in the pay of thoſe perſons who had the care of the engines. To this was added a conſiderable conſumption of oil and tallow over and above what was common to the old way of working; ſo that it has been more than mere conjecture that had they the advantages of the improvements in boring cylinders and in fitting up the other acting parts of the engine on the atmoſpherical principle, they would have been benefited nearly as much as they were by the new improvement. Here too we muſt be allowed to obſerve, that much of the merit aſcribed to the fertile mind of Mr. Watt really originated with Mr. John Wilkinſon, who was always foremoſt in the improvement of any thing which related to the iron foundery. It was there the true method of boring cylinders originated, and they were executed in a manner which has not ſince admitted of improvement: and whatever may be affirmed of the eminence of Mr. Watt as an engineer, it is ſtill in the minds of ſome yet in exiſtence that the firſt engines which were erected, particularly the Bloomfield engine, and the engine at Bedworth, exhibited but miſerable ſpecimens of his mechanical abilities. This declaration is confirmed by his own confeſſion in his application to the parliament for an extenſion of the term of his patent, where he ſays, "on account of the many difficulties which always ariſe in the execution of ſuch large and complex machines, and of the long time requiſite to make the neceſſary trials, he could not complete his intention until 1774," though he had his patent in January, 1769; nor muſt it be forgotten, that ſome ſterling acknowledgments are due to Mr. Watt's coadjutors, of which he availed himſelf in a region of rare talents*.

Nevertheleſs, let it be remarked that Mr. Watt took up the ſubject of improvement with a large and important object in view: it was not only to renovate the principle, but to aſſimilate this moſt grand aſſemblage of philoſophical and mechanical ſkill to thoſe machines which, on a ſmaller ſcale, had hitherto engroſſed the talents of our moſt ingenious artificers, and been the admiration of other nations wherever they came: nor do we mean to withhold the acknowledgment, that through his means it now ranks foremoſt among the productions of the philoſophical or mechanical world.

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* Theſe obſervations had not come into view, if it had not been for the partial, yea fulſome, compliments paid to this gentleman by the writer of the article *ſteam-engine* in the Encyclopedia Britannica.

In this ſhort hiſtory, however, we muſt not omit to notice a circumſtance known but to few. About the time that Mr. Watt was engaged in bringing forward the improvement of the engine, it occurred to Mr. Gainſborough, the paſtor of a diſſenting congregation at Henly-upon-Thames, and brother to the painter of that name, that it would be a great improvement to condenſe the ſteam in a veſſel diſtinct from the cylinder, where the vacuum was formed: and he undertook a ſet of experiments to apply the principle he had eſtabliſhed; which he did by placing a ſmall veſſel by the ſide of the cylinder, which was to receive juſt ſo much ſteam from the boiler as would diſcharge the air and condenſing water in the ſame manner as was the practice from the cylinder itſelf in the Newcomenian method; that is, by the ſnifting valve and ſinking pipe. In this manner he uſed no more ſteam than was juſt neceſſary for that particular purpoſe, which, at the inſtant of diſcharging, was entirely uncommunicated with the main cylinder; ſo that the cylinder was kept conſtantly as hot as the ſteam could make it. Whether he clothed the cylinder as Mr. Watt does is uncertain: but his model ſucceeded ſo well as to induce ſome of the Corniſh adventurers to ſend their engineer to examine it; and the report was ſo favourable as induced an intention of adopting it. This, however, was ſoon after Mr. Watt had his act of parliament paſſed for the extenſion of his term; and he had about the ſame time made propoſals to the Corniſh gentlemen to ſend his engine into that country. This neceſſarily brought on a competition, in which Mr. Watt ſucceeded; but it was aſſerted by Mr. Gainſborough, that the mode of condenſing out of the cylinder was communicated to Mr. Watt by the officious folly of an acquaintance, who was fully informed of what Mr. Gainſborough had in hand. This circumſtance, as here related, receives ſome confirmation by a declaration of Mr. Gainſborough the painter to Mr. S. More, late ſecretary to the Society for the Encouragement of the Arts, who gave the writer of this article the information; and it is well known that Mr. Gainſborough oppoſed the petition to the houſe of commons through the intereſt of general Conway.

Perhaps it may not be unacceptable to mention, that before this period an attempt was made to drain the deep mines in Cornwall by a new application of Savery's engine, for which a patent had been obtained by Mr. William Blakey, who propoſed to employ the expanſive force of ſteam, with an intermedium of air between it and the water: this air was to ſerve as a means of preventing the condenſation of the ſteam, by keeping it from coming in contact with the water. Great contention aroſe among ſome of thoſe who counted themſelves men of ſcience as to the practicability of ſuch a project: ſome giving it as their opinion, that if the principle were to be admitted it would be very difficult to apply it in mines, where it would require ten atmoſpheres at leaſt: while others, with exalted pretenſions, declared it poſſible to conduct its influence to the centre of the earth. But an accident terminated the event as to this engine in Cornwall, by one of the ſteam-veſſels burſting through the force of the ſteam, though much under the degree of power required for the end propoſed to the Corniſh gentlemen. This being the firſt date of the application of ſtrong ſteam to raiſing water, and, by an eaſy tranſition, to do any thing elſe, we ſhall give a ſketch of the boiler and fire-place of this engine, copied from the author's ſmall tract on the ſubject, publiſhed in French at the Hague, in 1776; (ſee fig. 9. pl. XXIII.) by which it will be ſeen, that the method of generating ſteam lately publiſhed in the Philoſophical Magazine has been made uſe of nearly thirty years ago, and has nearly as long ſince received its final condemnation: but ſuch is the degeneracy of man, that while the Academy of Sciences at Paris, and the delegates of the ſtates-general in Holland, were pluming the author with the gaudieſt expreſſions of their approbation, not one inſtance can be found where he received the encouragement he was led to expect.

But ſtill this engine is no other than Savery's engine, furniſhed with apparatus intended to open and ſhut the uſual communications by cocks and valves. The ſame may be ſaid of Papin's and Deſaguliers's engines; they were all nothing elſe than Savery's, without the advantage which Blakey had connected to it; and had nothing but a mere nick-name to conceal their legitimacy.

As to the application of the expanſive power of the ſteam to the purpoſe ſet forth by Mr. Blakey, or indeed we may ſay by Mr. Savery, it was by no means an impoſſible thing; but the difficulty would not be here to obtain veſſels capable of reſiſting the action of ten atmoſpheres, but how to preſerve them in a ſtate of ſecurity, the decay of veſſels placed in circumſtances like theſe, which cannot be acceſſible to the inſpection of the moſt diligent attendant, and the conſtant anticipation of probable evil circumſtances, muſt render life painful to endure. But there is another caſe which ought to be noticed, viz. the difficulty of preſerving the ſteam in the degree of temperature by which it was generated; for it is well known that it is condenſible to a very great degree by the common temperature indicated by the thermometer; and this extent of expanſibility is not to be obtained without the acceſſion of a ſuperadded quantity of heat. Then, unleſs the veſſels in which the ſteam is to operate are kept up to that temperature, the extra expanſion is annihilated. We have heard of patents being paſſed for this mode of uſing ſteam; but we never heard that we were to be forbid to uſe ſteam of any particular intenſity, eſpecially where caſes quite unexpected have compelled engineers to the prompt uſe of it as a neceſſary expedient; and we ſhould imagine that, after reading Mr. Watt's ſpecification of 1769, no perſon would attempt a monopoly of the uſe of ſteam at any intenſity whatever.

It ſhould be obſerved, that in treating on the principle and operation of the atmoſpherical engine thoſe who have taken up the ſubject have done it in a very looſe and imperfect manner, ſo far as relates to the power and effect; accounting for the loſs of the former and want of the latter from falſe premiſes: but we ſhall adjuſt that matter in a review of what has been publiſhed in the Encyclopedia Britannica, of the improvement of the ſteam-engine by Mr. Watt. This article ſeems to have been written for a different purpoſe than merely to inform the public of the gradations and accidents by which Mr. Watt accompliſhed his projected improvement; and either the writer muſt have been miſinformed, or he had greatly miſunderſtood the ſubject.

It has been an egregious error among thoſe who have taken upon them to diſcriminate the defects of Newcomen's engine, by expreſſing the effect for the power, ſaying, that the application of the principle to the purpoſe of pumping, &c. will not admit of more than ſeven or at moſt ſeven and one-half pounds per inch in the area of the piſton: but this is evidently a looſe unguarded expreſſion; for it is well known, that by attending to the various lifts of pumps in the engine-ſhaft of a coal or a copper mine, taking into the account the altitudes and the diameters, the friction of the buckets, and the water on the ſides of the pumps, the opening of ſtrong double-leathered valves, together with the ſtones and gravel that enter at the foot of the pump, the inertia of the pump-rods, the chains, the maſſive lever placed between the cylinder and the pumps, all operating againſt this ſeven and one-half pound, *if it were only ſo*, muſt have produced a very different effect to what has been done. The fact is, that with all theſe impediments, added to the friction of the piſton in a very bad cylinder, the columns of water *only* have been equal to ſeven and one-half pounds per ſquare inch on the piſton. This could not have been accompliſhed by ſuch a vacuum as afforded only a preſſure of ſeven and one-half pounds per ſquare inch on the piſton.

This has alſo been the outcry againſt the various attempts to improve boilers and fire-places; and the queſtion uſually was, on the report of ſuch a new boiler being ſet, "How many pounds do you get to the inch?" Surely it cannot but excite admiration, that the queſtion ſeldom or ever came to, "What can you do with a chaldron of coals?"

Another ſubject of complaint has been the neceſſity of a counter-weight to return the piſton for another ſtroke: this has been very ſeriouſly diſcuſſed by many who have had opportunities of ſeeing an engine in their ſummer's tour; and very ingenious formula have been invented to enable the practical engineer to come at the maximum of effect in engines particularly circumſtanced in this reſpect: and we are congratulated on the annihilation of the injurious effects attendant on this matter in the old engines by the improvements of Mr. Watt.

We are by no means diſpoſed to detract one atom from the advantages reſulting to the community through the perfection of Mr. Watt's engine: but we ſee it made uſe of for invidious purpoſes; not to elevate Mr. Watt above his inherent merit, but to ſubordinate every other profeſſional man in the ſcale of compariſon, to repreſs the energies of his cotemporaries, and give a deadly blow to competition.

The operation of the counter-weight in the atmoſpherical engine is not affected in the manner this writer has ſet forth: it may be ſo, indeed, in an engine conſtructed on purpoſe for amuſement or experiment; but we have to do only with engines prepared to ſome important execution, many particulars of which muſt ſubmit to exiſting circumſtances.

If we underſtand the preciſe meaning of the writer of this article in the Encyclopedia Britannica, it is, that in atmoſpherical engines the weight on the outer end of the lever is employed to overcome part of the preſſure of the atmoſphere at the return of the ſtroke of the engine: *that is not the caſe;* and we muſt firſt of all conſider what is the deſign of the engineer in giving or allowing a preponderance to that end of the lever. It is ſimply that the buckets may deſcend, and the piſton may riſe without any further combination of apparatus employed for that purpoſe. Now let us obſerve its operation in an engine juſt erected; in which caſe the mathematician and the unlettered artiſt ſtand on the ſame level in eſtimating the quantum of outſide ballaſt for the engine, with the water already up to the top of the pumps, or in other words to the level of the adit. But the ſteam being admitted into the cylinder, the operator ſhuts the ſteam-cock, and without any injection the engine makes a firſt ſtroke, though very quietly: perhaps he then gives ſteam again to the cylinder, and according as he feels the piſton's tendency to riſe, he ſuits his judgment to the degree of opening in the cock: if it riſes too ſlow, he puts old iron or ſtones upon the pump end of the lever; and if it riſes too quick, he places theſe weights on the inner end. Here then are three important circumſtances to be attended to in this regulation: firſt, that the pump-buckets ſhall deſcend, but without ſuch force as ſhall endanger the breaking of the pump-rods; ſecondly, that this deſcent ſhall nevertheleſs be as quick as poſſible; but, thirdly, that it ſhall not impede the diſcharging functions of the engine: and here are three caſes before which the vulgar ſtoker may turn up his noſe at the acuteſt mathematician in the world; caſes to which the higher powers of the human mind muſt bend in ſilent ſubjection to mere mechanical inſtinct.

It is the firſt object (when an engine is erected on a mine), to get out the water with the leaſt delay poſſible; and at this time the engine goes ding dong, night and day: but as the water gets down, this counter-weight muſt be adjuſted, if the rods were hung on for more than one lift of pumps: the principal thing within the engine indicating the neceſſity of this adjuſtment is the *diſcharging* of the engine, *getting rid of the air and condenſing water*; and unleſs theſe are performed punctually the engine ſoon ceaſes to work. Now, neither the air nor the water can be diſcharged inſtantaneouſly, but require a certain time in proportion to the quantity of each and the degree of ſtrength in the ſteam; and therefore the piſton muſt not riſe ſo quick as to prevent the ſteam's action on the air and condenſing water, which it will do when the engine is thus employed, and the ſteam is low; for if the piſton aſcends faſter than the boiler ſupplies there can be no diſcharge, and after a ſtroke or two the engine will ſtop.

Now, then, let us ſee how far this counter-weight has to do with "overcoming the unbalanced part of the preſſure of the atmoſphere." It is granted on all hands, that working ſteam muſt more than balance the preſſure of the atmoſphere; and where this is not the caſe (except in very lightly burdened engines) the engine will ſtop, as juſt now obſerved; yet not by want of any thing to balance the atmoſpheric preſſure on the piſton, but for want of ſteam ſtrong enough to diſcharge by: for let the counter-weight be ever ſo ſmall (and in engines heavily loaded we are obliged to let the pump-end preponderate but ſlowly), unleſs the engine is a very bad one, a moderate ſupply of ſteam will reſtore the equilibrium: nay even no ſteam at all, if a ſpigot is taken out of the flanch piece at the ſnifting clack, to let in the air.

But without any reflection on the application of ſteam on the piſton, which we are given to underſtand is one ground of ſuperiority over the atmoſpherial engine, there is an advantage in the atmoſpherial engine in this point of view which Mr. Watt's ſingle engines cannot admit.

It is well known, that when a mine is going down, and the engine-ſhaft is conſtituted to receive all the water from different parts of the mine, that the gait of the engine muſt depend on the uniform influx of the water, and the engine muſt be ſo nicely regulated to this quantity of water as that it muſt ſup it up at every ſtroke. Now, if this ſupping is violent, the air which enters at the concluſion of the ſtroke will, at the return of the buckets, blow a deal of the water out of the pumps, which will fall to the bottom, and become ſo incommodious as to prevent the miners from working; and on the other hand, if the ſtrokes of the engine are not quick enough the water will gain on the men, and they muſt give over working.

Now the old engine man can retard or accelerate the ſtrokes of the engine, merely by the regulation of the fire; for, if the engine ſhould return too quick he lets down the damper, and if it is too ſlow he raiſes the damper: by theſe means, he can vary the action of the ſteam on the nether ſide of the piſton from 0 to 2 pounds on the inch over the preſſure of the atmoſphere, which in a ſixty-inch cylinder will be from 0 to 7200 pounds: this cannot be done in the new engine; for the piſton riſes in one uniform medium. Thus is this counter-weight relieved from the charge of hinderance to the engine, and proves to be of importance rather than impediment; particularly when it may be depended on that it may be ſo adjuſted as to admit the elaſticity of ſteam to have a great ſhare in the power of the engine: for let the counter-weight be ſo adjuſted as to leave all in equilibrium; then it is manifeſt, if the engine will work at all, it muſt be by the elaſtic force of the ſteam acting on the under ſide of the piſton: and to compenſate that quantity of ſteam we have the ſuperabundant weight on the piſton-end of the lever to act in concert with the preſſure of the atmoſphere; which in the caſe ſtated above, in a cylinder of 60 inches diameter, may be ſo much as 7200 pounds.

Concerning the ſtate of the vacuum in the old engines we know but little; but it muſt be conſiderably more than has been ſuggeſted: for an engine carrying a load of 7½ pounds on the ſquare inch of the piſton, together with the friction and inertia, eſpecially in large engines, can hardly be leſs than 14 pounds on the inch.

The writer of this article, about thirty years ago, tried the vacuum of ſeveral engines in the county of Cornwall; and one which was reckoned the leaſt brought the gauge to 23, and ſometimes

24. If we take the extreme, it will be 11.6 pounds on the ſquare inch: but that is not enough to work an engine with that load, taking in the other conſiderations; and we have no heſitation in ſaying, that where engines have raiſed a column of water equal to 7½ pounds on the inch of the piſton it muſt have little inertia and friction, or it muſt be laid to the account of the aforeſaid impulſe of the ſteam in elevating the piſton.

This was one way which Mr. Gainſborough propoſed to increaſe the power of an engine then erected in the county of Cornwall, in a mine which ſtood in need of ſome prompt aſſiſtance: but the timid had the majority; and Mr. Gainſborough having it not to boaſt that he had erected ſeveral large engines as ſpecimens of his invention, could not come forward with the ſame confidence and ſucceſs as Mr. Watt. But had Mr. Gainſborough ſucceeded to have a fair experiment with a good cylinder, and have accepted a reaſonable premium, Mr. Watt's engines would not have obtained the degree of celebrity they ſo ſoon acquired in that county.

Since the application of the ſteam-engine to the purpoſes of giving motion to mill-work, it has been a deſideratum to maintain an uniform force or action on the crank, in order to have the ſame effect on the fly.

When the engine was firſt applied for the purpoſes of rotation, it had not then the advantage it has at preſent of the double ſtroke; and the mode of equaliſing (as near as could be in thoſe circumſtances) the working and returning ſtrokes was by making the rod which connected the engine and the mill together (and ſtill called the connecting rod) equal to half the power of the engine, being of caſt-iron; and when the weight was not in the rod, it was laid on the lever at that end: but this could not well apply by the old engine, except in caſes where the work was nearly the ſame throughout the day; for as the diſcharging muſt be performed at every ſtroke, it would require a quantum of ſteam proportionate thereto, and that invariably; ſo that in breweries, and thoſe works which demanded attention to varying reſiſtance, this could not apply; for when they had ſtruck off the grinding, for inſtance, if ſomething did not operate to retard the effect of the counter-weight, the engine would increaſe in its gait beyond all bounds, ſo as to work itſelf to pieces: and as the only remedy was to check the quantity of ſteam at the returning ſtroke, ſo the diſcharge muſt be interrupted, and the engine muſt ſtop. But Mr. Watt's ſingle engine accommodated this circumſtance, from the mode of diſcharging being conſtant, and not poſſible to be effected by the work applied to it, be it uniform or variable: hence to leſſen the momentum of the rod it was only to check the entrance of the ſteam, by any contrivance that would prevent the plenum valve from opening to its greateſt limit.

One mode of giving a uniform action on the crank was attempted in an engine erected about nine years ſince at the brewery of Meſſrs. Meux and Co., where the power was at a conſtant diſtance from the centre of the lever, while the other end, which was connected to the crank by the connecting-rod, varied nearly its whole length.

This engine had two cylinders in alternate action on a band-wheel by means of two chains. The wheel which carried the connecting-rod was fixed on the ſame ſhaft with the band-wheel, and had a pin near its periphery on which the connecting-rod was attached. This pin traverſed about 120° of the whole circle, and may be denominated the end of the lever, which, in its action upward and downward, acceded and receded to and from the centre of motion; and had it traverſed through the remainder of the ſemicircle it would then have preſſed on the crank, proportionate to the ſines of every angle it makes in its revolution. But conſidering the infinite preſſure on this pin in the crank-wheel, it would have demanded a degree of ſtrength at that part, which would have been prepoſterous compared with the reſt of the work. See the ſketch of this contrivance at fig. 13. pl. XXX.

This engine has its merits and its defects: it is ſubject to a deal of friction, by having double cylinders, and their appendages; and unleſs the communication between the cylinders is clothed with the beſt materials for that purpoſe, a great loſs of heat muſt enſue. From the unfiniſhed ſtate in which the engineer left it, and the prejudices of the proprietor, and the people he employs about it, we can hardly imagine that it can have derived much advantage; but the work uſually laid on it was, the grinding with four pairs of ſtones, the liquor-pump, houſewater-pump, ſtanding-pump, beer-pump, wort-pump, maſhing-machine, beſide ſack-tackle, all at once, and a very extenſive communication by vertical and horizontal ſhafts, in which alone the effect was equal to thirty-eight horſes, according to Boulton and Watt's eſtimate. Its form was ſuch as to admit an appearance of novelty and elegance; and might have been ſo modified as to abridge much of the principal defect, had it not been for the glorious uncertainty of the law.

If it had not been for the negligent manner of delineating and explaining the principles of Mr. Watt's engine in the Encyclopedia Britannica, we needed not have gone any further into the matter than merely to particulariſe ſome circumſtances which chance or deſign is ſeemingly always calling forth at this period of philoſophical inquiry: but let any judicious mechanic look at the plate containing Mr. Watt's engine in that Encyclopedia, and then let him ride from Berwick-upon-Tweed to the Land's-end, and ſee if he can find ſuch an one, or if he can hear tell of ſuch an one being erected any-where.

If we are right in our conjectures, this fly at the piſton-end of the lever, together with many other fanciful and ridiculous projects, were inſtituted to equaliſe the action of the ſteam in its expanſive force on the piſton, according to the diſcovery noticed by Mr. Watt's hiſtoriographer at No. 70, article Steam-engine: all which may be found in the Rolls chapel, where Mr. Watt's ſecond ſpecification on ſteam-engines is ſafely depoſited. But if this drawing is given as a ſpecimen of the ingenuity of the inventor, it muſt have been intended according to the inverſe ratio of things.

We ſhall therefore preſent our readers with a genuine application of the principle of Mr. Watt's engine, as far as is poſſible in a work of this extent. But the whole volume would not have afforded ſpace ſufficient to develope and exemplify many particulars which muſt paſs unnoticed here; not on account of their inſignificance, for the ſmalleſt parts are to the whole as the hand or the foot to the body: but it will be neceſſary to obſerve here, that within theſe five-and-twenty years we have a ſpecies of ſteam-engine invented, which until then was not known; and that is the ſteam-engine applied to produce a rotative motion from a reciprocating one, whereas the other is applied principally to pumping water from mines, &c.; and each will require a diſtinct conſideration. The engines uſually erected for drawing water have been what are termed *ſingle* engines; though there are not wanting inſtances enough where the *double* engines have been applied to that purpoſe; ſome of which we have ſeen ſo unwieldy and complicated, that it ſeemed to us like the ſport of genius having nothing elſe to do. It is true it was in a latitude where money bears no compariſon with the calls of the moment, and where beauty and ſimplicity have no charms. But while we touch as lightly as poſſible on many other particulars, we muſt cenſure exceedingly that enormous aſſemblage of materials which, even in a ſtate of reſt, tend powerfully to cruſh each other; but when put into motion by ſuch a powerful agent, the relaxation of which depends on the connection of a wooden pin perhaps, or a ſtrap of leather, we deem it not inconſiſtent with the province of an engineer to aſſign a limitable magnitude to machinery of this ſort, without being ſatisfied of the practicability of the accompliſhment: it is a daring outrage of art upon nature; for the former may have the knack of piling together, nature has not the like facility in preſerving texture, componency, diviſibility, &c. eſpecially under preſſure and agitation, like what is to be obſerved in a double engine of a ſixty-ſix inch cylinder *; yet it is recorded in the Encyclopedia Britannica, that the engine at the Albion Mills, though the largeſt in the kingdom, had its movements ſo judiciouſly contrived and ſo nicely executed, that not the leaſt noiſe was heard, nor the ſlighteſt tremor felt in the building !!!

In giving a clear explanation of the principle of this machine, it will be neceſſary to deviate from the preciſe diſpoſition of the parts as they are uſually put together: but in fig. 1. pl. XXX. this deviation is very little, and repreſents a ſingle engine. A the cylinder in which the piſton moves, B the ſteam-pipe, D the condenſer, E the diſcharging-pump, F a bottom common to the pump and condenſer, in which is an occaſional communication by a hanging valve at F: *g* is a valve to be lifted by the engine at every ſtroke, for the purpoſe of condenſing the ſteam; *h* is a valve placed outſide the ciſtern (of which *x x x x* is a ſection on purpoſe to ſhew the contents), but communicates only with the condenſer by a pipe paſſing through the ſide of the ciſtern, and is inſerted at the ſide of the condenſer; *i* is a valve to be lifted by the engine, and opens a communication between the cylinder and the condenſer; *k* is a valve to be lifted by the engine, and opens a communication between the lower part of the cylinder and the ſteam-pipe; and *l* is alſo a valve of the ſame kind, opening a paſſage from the boiler to all parts of the engine.

The piſton-rod, which is here broken off at *m*, is connected by a chain to the lever or beam, which is ſupported on a wall of good maſonry, with proper pivot-blocks for ſupport to the gudgeons; and as this kind of engine is uſually employed for pumping water, another ſet of chains at the other end of the beam is appropriated to connect to the pump-rods.

Then to ſet the engine to work, the firſt thing is to lift the three valves *i*, *k*, and *l* (for which there are apparatus too minute to lay down on this ſcale); theſe being opened, the ſteam occupies every cavity and crevice of the engine, and in a little while diſplaces all the air in the cylinder, condenſer, &c. which is diſcharged at the valve *h*: this valve is always covered with water in a ſmall ciſtern attached to the ſide of the large one; for it is hardly in the power of art to fit it to that degree of accuracy as to enſure its tightneſs: but here the air is diſcharged at firſt ſetting the engine to work; and this valve is called the *blowing* valve. When the cylinder and other veſſels are properly heated and the air diſcharged, which is well known by a very ſmart crackling noiſe at that valve, like a violent decrepitation of ſalt in a fire *: theſe valves *k* and *i* are to be ſhut; and after waiting a few ſeconds, gently open the valve *i*: and if the engine does not move, the injection-valve *g* muſt be opened a little †; and if the engine does not move, then the operation of blowing muſt be performed again, though but for a few ſeconds, and the engine in general will go off ſmartly ‡.

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* It is better in many reſpects to have two moderate ſized engines than one of theſe unwieldy things, but particularly for management and durability. It is with regret we recollect an error of this kind by one of the firſt engineers this country ever ſaw, where he erected one of thoſe machines, the lever of which was ſo large as would require a cylinder equal to the power of near 40 horſes to give it motion.

In treating on this ſubject, it is neceſſary to obſerve, that if we were to attempt a thorough information to the various claſſes of readers into whoſe hands this may come, it muſt have been taken up on a ſcale of greater magnitude than what is conſiſtent with the plan of this publication: we muſt therefore ſuppoſe our readers are not entirely ignorant of the general outline of this invention; to ſuch readers only will theſe explanations be of any importance.

In all engines on this principle, it is neceſſary that the parts appropriated to condenſation of the ſteam ſhould be kept as cold as poſſible, and that thoſe parts intended for the operation or paſſage of the ſteam be kept as hot as poſſible: hence the diſcharging-pump § and condenſer are placed in a ciſtern of cold water kept conſtantly full, and a little running away; and if the injection-valve is placed low in this ciſtern, it will take the water in the coldeſt ſtate. See the injection-cock in fig. 2.

As the condenſer is immerſed in water to be kept cold, ſo the cylinder ſhould if poſſible be immerſed in ſteam to be kept hot: for which purpoſe Mr. Watt formerly uſed a caſing round the cylinder, and at the top and bottom; and this would have been attended with very beneficial effects if it did not enlarge the ſteam ſurface, and expoſe it to a more rapid condenſation when it ought to be preſerved; for to have the vacuum as perfect as poſſible, it is neceſſary that the cylinder be kept up to ſuch a temperature as to prevent the leaſt condenſation on the internal ſurface either above or below the piſton: becauſe, if the ſides of the cylinder were to be wet, as in the common atmoſpherical engine, the vacuum would be vitiated, as it is there occaſioned by this wetneſs or moiſture gradually forming to ſteam, which the outſide caſing prevents, being filled with ſteam from the boiler. But if it were poſſible to cover this outward caſe with any ſort of ſubſtance which would entirely prevent the tranſmiſſion of heat *for that caſing*, it would ſuperſede the uſe of the caſing altogether, and would apply with more advantage to the cylinder itſelf. But we do not know of any ſubſtance which will not admit this tranſmiſſion more or leſs. They who wiſh for information on this ſubject may find it in count Rumford's Eſſays.

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* This noiſe is occaſioned by the air being all gone, and the water producing a ſudden and rapid condenſation of the ſteam.

† The valve *i* being opened, there is a paſſage made from the cylinder to the condenſer; but on account of long blowing, the ſides of the condenſer become hot, and the water in the ciſtern hot likewiſe: ſo that the condenſation muſt needs be very ſlow, even at the firſt injection of the water into the condenſer.

‡ We believe, that until Mr. Watt went into Cornwall, this blowing valve had never been applied to any of his engines, it being the uſual method to pump out the air by a temporary brake attached to the diſcharging-pump; and that this valve was firſt applied by Mr. Hornblower at an engine on a mine called Ting Tong; which engine he put up for the *proprietors of the work*, not for Meſſrs. Boulton and Watt.

§ We chooſe to call it thus from the nature of its office. It diſcharges all whatever comes into the engine, but eſpecially the water and the air; and it is no more an air-pump than it is a water-pump, excluſively; in fact, it is both.

But the firſt circumſtance of importance to the proportion and diſpoſition of the ſeveral parts, is the ſolidity of the veſſels and the perfection of the joints. Copper tubes are apt to be unſound at the ſeams, and other parts which are required to be bent out of a right line; and iron caſtings, which require any particular ſort of ſtay in the moulding to keep the core from the outſide, as theſe ſtays are made moſtly of wrought iron, they contract more in cooling than the caſt-iron does about them, even ſo as to become looſe ſometimes; in ſuch caſes, it is unutterably perplexing to find out the places or cauſe of this defection; the joints are ſuſpected for the moſt part, but even remaking them ſometimes proves no amendment; and this muſt be the cauſe in general why one engine from the ſame patterns is better or worſe than others. And we have reaſon to fear that this matter of complaint is on the increaſe; for ſelf-intereſt has ſo powerful a preponderancy, eſpecially in the metropolis, that we ſhall deſpair of having theſe objects regarded as they were formerly; ſemblance being for the greateſt part the order of the day.

Mr. Watt has adopted a gauge (very improperly called a barometer), to indicate the degree of vacuum in his engines; and we deem it of important conſequence to the well-going of the engine, the profit of the proprietor, and the credit of the engineer: yet in many engines in London we ſee this important inſtrument either out of repair, or wholly laid aſide. The form is given at fig. 3. They have been made of glaſs; but if the quickſilver is not very pure, the alloy with which the venders of this article adulterate it is by conſtant action brought to the ſurface, and that and the vapour together make the tube ſo foul that no preciſion can be obtained. Iron therefore is the beſt material: both parts of the tube ſhould be correctly of one diameter, or elſe the reſult will be erroneous. This tube muſt communicate with the condenſer by a ſmall copper pipe, and a ſtop-cock be placed between the gauge and condenſer. The index in this inſtrument is a light deal rod, which is put into the ſhorter tube; and quickſilver being poured into it within three inches of the end, the rod is put into the tube, and it floats on the quickſilver. It is almoſt needleſs to remark, that the graduations on this inſtrument muſt be inverted with regard to thoſe of a ſingle tube.

Perhaps it ſhould have been noticed before, that the rod of the diſcharging pump is connected with the lever at ſome point determinable by the length of the ſtroke; and in this figure it riſes with the piſton, and brings up the air and water with it, both of which are diſcharged at the branch *p*, in which is a hanging valve opening outward.

It is intimated in the large account of Mr. Watt's engine, that this is the moſt preferable mode of working this pump, viz. at the inner end of the lever; but we do not ſee why: as far as our judgment would lead us, we ſhould prefer the outer end, where the conſtruction will admit of it; and we think we have ſeen ſome engines ſo conſtructed that have made a better vacuum than when it is connected inſide: depending, as we think, on an impulſe given to the remaining air of the laſt ſtroke at the inſtant the bucket begins to riſe; for no ſooner is the valve *i* opened than the ſteam ruſhes towards the condenſer, and giving a momentary tendency to a plenum, does give a puſh to the air through the hanging valve between the pump and the condenſer; and hence we are warranted to conclude, that more air enters the pump by this means than if it be left to its own expanſion.

We muſt obſerve how this pump affects the power of the engine. By ſome obſervations of thoſe who have conſidered the ſubject, we ſhould be led to conclude, that it is an addition to the load of the engine: but if we attend to its conſtruction, having a valve to keep off the preſſure of the atmoſphere, it is certain it can have but little weight until the bucket is near the higheſt limits of the ſtroke; and taking the ſum of the reſiſtance from the commencement of the ſtroke to its termination, it will be found to be very little in compariſon with the power of the cylinder. But if the weight of the atmoſphere was conſtantly on, it could make no other difference in a well-conſtructed engine than what ariſes from the friction.

From ſome authentic reports on the ſucceſs which attended Mr. Watt's labours in applying the principle of this engine, it appears he did not imagine it would require ſo large a portion of the content of his cylinder to be transferred to his pump as he afterwards found neceſſary [*]. And on this account, one experiment among many others, which is related in the Encyclopedia Britannica, we muſt be permitted to enter our proteſt againſt: it is this, viz. ſection 57, "a globular veſſel communicated by means of a long pipe to a cylinder of four inches diameter and thirty inches long: the globe was immerſed in water: the pipe had a ſtop-cock: the cylinder was filled with *ſtrong ſteam*: the cock was turned (nay ſcarcely turned), when the ſides of his cylinder were cruſhed together like an empty bladder."

Not to notice the ſtriking figure of the cruſhing, let us take a view of the experiment: a veſſel of the form of a ſphere was connected to the cylinder by a pipe of an inch diameter; this veſſel was immerſed in the water *unexhauſted*, we may fairly ſuppoſe: the cylinder, containing 390 cylindrical inches, was filled with ſtrong ſteam; the cock was hardly turned when a complete vacuum took place in the cylinder.—Now the credibility which the relation of this experiment demands muſt depend on ſome particulars unrelated by the reporter: for if we admit that this globe and a part of the pipe alſo contained the air of the atmoſphere, what could there be, beſides mere magic, to induce the ſteam to leave the cylinder in ſuch a hurry? No: we have ſeen the experiment tried again and again; and the naked truth is—*it cannot be.*

We will advert to another experiment or two of this kind. Encyclopædia Britannica, Steam-Engine, ſection 10. "Experiments have been made on ſteam-veſſels, ſix feet in diameter and ſeven feet high: and it has been found that about four ounces of water as warm as the human blood will produce a complete condenſation in leſs than a ſecond." "In another experiment with the ſame veſſel, no cold water was allowed to get into it; but it was made to communicate by a long pipe four inches diameter with another veſſel. The condenſation was ſo rapid, that it could not be meaſured." Upon theſe experiments a deal of hypothetical reaſoning ſucceeds, all which is evaporated in the Supplement to the above work. See STEAM-ENGINE.

Now here is a fact related, which afterwards is acknowledged to be no fact at all. We ſhould not have thought ſo much about it, if it had not been related ſo circumſtantially. So, in the experiment made with ſuch ſcrupulous care as the expanſion of boiling-water in a veſſel holding 12600 grains of ſteam, which weighed not more than one grain; making the expanſion to a certainty 10000 to 1: and here, in the Supplement aforeſaid, it comes to 1800 to 1. Now the queſtion is, Which of them is true?

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[*] In the beſt engines we have ſeen or heard of, this proportion is not leſs than one-eighth of the content of the cylinder for a ſingle engine.

But, to proceed:—The moſt novel circumſtance in the operation of this engine is, that when the ſteam has been permitted to act on the piſton to the limits of the ſtroke, it has permiſſion to enter the cylinder a ſecond time *beneath* the piſton; and ſo the piſton riſes in a medium of ſteam more or leſs rare as it happens: nor is that point of any ſignificance, even if it were all to be condenſed in its paſſage from the upper to the nether ſide of the piſton; and it is a beautiful accompaniment of the prime object of the improvement. To make this part of the evaporation as perfect as poſſible, the valve *k* ſhould be placed at the top of the pipe B, juſt under the valve *l*; otherwiſe that pipe full of ſteam is waſted every ſtroke.

But it generally happens in engines erected for pumping water, that they are calculated to go deeper than the preſent bottom of the mine; and therefore, if all the ſteam which enters the cylinder for one ſtroke was to be condenſed, the engine would act with its whole power, and the effect would be to deſtroy itſelf: on which account, in engines thus circumſtanced, the injection is to be ſtopped long before the termination of the ſtroke, which leaves a reſiduum of ſteam at the bottom of the cylinder, that proves an effectual banking to the piſton; even ſo far as to ſupport it while the chains to which it is appended are become quite ſlack by the momentum given to the lever during the action of the ſteam on the piſton. We believe it was this circumſtance that indicated to Mr. Watt the advantage of ſhutting off the ſteam from the boiler ſoon after the commencement of the ſtroke; which is done in the following manner.

The valve *l*, the office of which is to open or ſhut the communication between the cylinder and the boiler, is ſo particularly connected with the working gear, that by altering the place of a pin it is ſhut ſooner or later, as occaſion requires; and when the piſton has proceeded half way down, if this valve is ſhut at that inſtant, the piſton is carried through the remainder of the ſtroke, partly by the momentum it has already acquired, and partly by the remaining expanſion of the ſteam, which, notwithſtanding its growing rarer and rarer, is ſufficient with its momentum to complete the ſtroke.

We have obſerved, that in order to give action to the engine at its firſt onſet, and indeed at every ſucceeding ſtroke, the valve *i* is to be lifted. This valve is kept down by a weight equal to the preſſure of the atmoſphere, added to the elaſticity of the ſteam above that preſſure; there being a vacuum beneath it, and the action of the ſteam upon it. Hence, in large engines it requires a great force to lift it up, in ſome engines equal to 1000 or 1200 lbs. and it muſt be lifted in an inſtant, if poſſible.

The uſual method of doing this was by an apparatus being a part of the working gear, conſtructed after the following manner. Let *c*, fig. 4. be the centre of the ſection of a ſtrong bar of iron about two inches ſquare: on one of the angles of this bar a piece of iron, in the form repreſented at *b*, is welded on; and on the next ſide but one there is an arm fixed in the form *d*. This bar, which is uſually about three feet long, or little more, is made to work between two poſts, and is called a Y ſhaft, and the poſts are called Y poſts, conformably to the old plan of working gear. This Y ſhaft, with its arm *d*, is brought to the poſition ſhewn in the figure to be ready for opening the valve, when a ſmall pin in the plug *p* lifts a detent *x*, that is made to preſerve the whole in its proper poſition, and a balance-weight *w* brings this arm or branch into the action of turning up againſt the ſpanner or lever *h* attached to the valve *v*, and working on the ſpindle or centre *g*: by this means here is a very powerful force at the firſt inſtant applied to the very end of the lever *h*, which is continually diminiſhing as the valve riſes; for the preſſure on the valve and the very end of the lever is, or ought to be, exactly the ſame in every poſition of the crooked arm.

Still it was a heavy load on the hand to manage this part of the working gear; and in converſation on the ſubject, it was ſuggeſted to Mr. Watt to make theſe large valves of two valves, that is, by making a ſmaller-ſized valve in the middle of the large one, and then, after the ſmaller one was lifted a little, the whole would riſe together—and it was adopted: but it being difficult to keep in order ſo as to be tight, we believe it was laid aſide.

We cannot help taking notice of another illiberal inſinuation of the writer of this article in the Encyclopædia Britannica: when in ſetting forth a contrivance to render the opening of this valve as eaſy as was poſſible, and which was abſolutely invented at an engine at Radſtock near Bath, he ſays, " it has been ſervilely copied from Mr. Watt," as if it could not be copied from any one beſides; and if copied, it muſt be copied *ſervilely*: now although hundreds are ſaid to have copied from Mr. Watt, it might rather perhaps have been ſaid Mr. Watt copied from hundreds *. But it does not appear that the writer underſtood the *modus operandi* of this wonderful project, by the figure he has given of it, or by what he advanced in the text, both of which are alike falſe. He ſays, "though the valve has not moved the hundredth part of an inch, the preſſure is over." It would be waſting time, and an affront to the underſtanding of our intelligent readers, to go about formally to prove the reverſe of this aſſertion; but as he has ſo awkwardly repreſented it, we will explain it at fig. 6.

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* We do not directly implicate Mr. Watt as being the illiberal coadjutor in this indiſcriminate ſcandal and defamation: but it would not

Let A be the valve, BB a lever attached for the purpoſe of raiſing it; CC is a rod with a joint in it at *i*; D is an arm ſtretching horizontally, with a weight W hung to it. This arm D and the part of the pointed rod C have motion round the centre O: ſo that when the weight W is at liberty to fall, it carries the arm D round the common centre downwards, and raiſes C round the ſame centre upwards in the direction of the dotted arch, at which the whole apparatus aſſumes a new poſition according to the dotted lines. From this ſketch, the principle by which this valve is opened may be eaſily comprehended: but it muſt be added, that this valve is not opened by the plug (here, and throughout in the Encyclopedia Britannica called the plug-frame), but by the action of a weight which is raiſed by the plug*.

It is neceſſary to the good performance of an engine, that this valve be opened as ſuddenly as poſſible, that the ſteam may have its releaſe quite inſtantaneouſly, if it could be done; for until the valve is opened the engine has not its full power. Hence the reaſon why in the beſt engines univerſally a weight or ſpring is applied to open it, and all the plug does is to return the weight to its former elevation.

But a much better method than this, or any of them, has been ſuggeſted by *a delicate* thought of Mr. Joſ. Hornblower, of Charewater near Truro, and conſiſts in conſtructing the valve on an entirely new principle: we ſhall give a repreſentation of this valve in fig. 7. AAAA, is the box containing the valve, BB is a valve inverted, and fixed firmly to the bottom of the ſocket S; this ſocket ſerves as a guide to that part of the valve that is to be lifted by a ſhort cylindrical rod, as is very common.

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have diſhonoured him if he had, in the ſupplement to this farrago of falſehood and abſurdity, demanded a recantation of whatever may have been previouſly inſerted either through prejudice or miſinformation; and we would never have interfered with the diſguſting panegyric that pervades the whole ſubject.

* The plug is that vertical piece of timber which is alternately riſing and falling by the motion of the engine; and by the pin's being ſet into particular holes, the ſtroke of the engine is adjuſted to a very great nicety.

The part which is to be lifted is DD EE: which lifting is performed by any of the uſual methods attached to the eye F, which is a part of the croſs-bar EE in the figure below, which is a plan of the upper ſurface of the valve and upper ſeat; for it muſt be obſerved that it has *two ſeats*, and that the principal paſſage for the ſteam is at the lower ſeat; for the ſteam in its paſſage goes down through the body of the valve: indeed it has always acceſs to the lower ſeating, the body of the valve being entirely open, except what is taken up by the croſs-bar EE; ſo that in this ſenſe we lift the thickneſs of the metal only of which the body of the valve is conſtructed. To help our ideas of the operation of this valve, we muſt conceive the upper ſpace in the box to be always full of ſteam, and conſequently the inner part OO of the valve (which, for better underſtanding it, is ſhewn by a ſection along the croſs-bar); then the lower ſpace of the box will be a vacuum, when upon lifting the valve (which is a cylinder open at both ends) the ſteam will paſs through it, and into the lower ſpace at the inverted lid BB. In this figure the cylinder part is raiſed a little, to ſhew how it ſeparates from the lower lid BB.

We have preſumed on this mode of applying the principle, not knowing the preciſe manner in which the inventor has thought moſt proper to do it; but we have no doubt of its being a very welcome improvement in thoſe large engines in the county where he reſides.

Adverting to the other parts of the engine, fig. 1. On the top of the cylinder *n* is a box to contain ſomething ſoft, yet pretty cloſe, *but not leather*, to embrace the piſton-rod *m* in its motion up and down: and this is uſually a ſort of plaited rope of white yarn, nicely laid in and rammed down gently, occupying about a third of its depth: then upon that is placed a ſort of tripod, having a flat ring of braſs for its upper, and another for its lower, part; and thoſe rings are in breadth equal to the ſpace between the piſton-rod and the ſide of the box; that being put on over the end of the piſton-rod, another quantity of this rope is to be put upon it, and gently rammed as before: then there is a hollow ſpace between theſe two packings, and that ſpace is to be ſupplied with ſtrong ſteam from the boiler. Thus is the packing about the piſton-rod kept in ſuch a ſtate as to prevent the air from entering the cylinder when at any time there may be a partial vacuum above the piſton.

This then is a deſcription of Mr. Watt's improvement as to what he originally had in view, and as to what preſented itſelf in perfecting his primary notions of the conſtruction; and in addition to what is paſt, we have only to recapitulate the references belonging to the figure 1. A repreſents the cylinder with its piſton ſuppoſed to be within it; B a pipe occaſionally communicating with the upper and lower ſide of the piſton; E the diſcharging pump with its bucket within; *y* its diſcharging nozzle with a hanging valve opening outwards; O part of the bucket-rod to be connected with the great lever; D the receiver or condenſer, having communication with the cylinder by the valve *i*; F the place of a hanging-valve placed between the pump and receiver opening towards the pump; *g* the injection-valve; *h* the blowing-valve, the outer part of it being immerſed in water in a ſmall ciſtern; *x x x x* a ſection of the condenſing-ciſtern, to ſhew the lower parts of the engine; *k* a valve for opening a communication between the upper and nether ſides of the piſton; *b* is a box and valve, for receiving and giving the ſteam from the boiler; *n* the box containing the packing for the piſton-rod; and *m* part of the piſton-rod broken off for want of room.

Such was the moſt perfect ſtate of Mr. Watt's engine until circumſtances demanded what was impoſſible, at leaſt what ought not to be. It was found that ſome of the mines in Cornwall, already at a great depth, wanted to go ſtill deeper; but, alas! no ſingle engine, unleſs it were a monſter, could be large enough: but "Mr. Watt's genius, always fertile in reſources," found out the means of making two engines in one, and the double-ſtroke engine came forth in two-fold cumbrous majeſty to what had ere been ſeen before. It would take more room than is allotted to this department to develope the enormous limbs and features of this creature as ſet up at ſome of the mines in Cornwall: which, even on a more manageable ſcale, applies but very diſcompoſedly to drawing, or, as we ought to ſay, thruſting, water from ſuch a depth.

But it is here in London and its vicinity that he has applied the principle to a purpoſe that enobles both him and it, and where we conceive it to have reached its acme both in deſign and execution.

We have repreſented this mode of working at fig. 2. where we muſt deviate largely from the practical application, in order to give a comprehenſive explanation. A is the cylinder, as in the ſingle engine; B is a pipe appropriated to deliver the ſteam from the boiler through the branch L; from thence it enters the cylinder alternately by the valves *v*, *w*, both opening towards the ſteam ſide. The pipe C has alſo two valves, one at the upper end of the pipe in the box *t*, and one which we muſt deſignate at the joint *r*, both opening toward the cylinder. The condenſer D has a blowing-valve, like the former figure in the ſingle engine; but the injection is made by a cock G, which has a pipe reaching near the bottom of the ciſtern; and when the engine is at work this cock is always open, and the injection always running in, becauſe the ſteam is conſtantly coming from the cylinder either above or below the piſton, and its operation is as follows:

When the air is blown out of the engine, and the piſton happens to be in its upper ſituation, the valve *v* on the ſteam ſide is lifted, and the valve *r* on the exhauſting ſide is opened: the exhauſting-valve *r* takes the ſteam from below the piſton, while the ſteam by the valve *v* enters on the upper ſurface, and a ſtroke is made; and at the inſtant the piſton comes to its place at the bottom of the cylinder, theſe valves are both ſhut, and the valves *w* and *t* are opened, and the upward ſtroke commences, and ſo on alternately.

It muſt be obſerved here that, whereas the piſton in the ſingle engine is pendant on the lever by the chains lying in the arch of the inner end, this muſt be connected by a mode that ſhall render the rod rigid in its action upward; for which purpoſe there is a ſyſtem of tranſverſe joints which compel the rod to a motion parallel to itſelf, exhibiting at once a moſt ingenious and pleaſant piece of machinery. At the other end of the beam or lever is a rod which connects the motion of the engine to a fly; and Mr. Watt has choſen to do this by a very ingenious application of one wheel fixed on the axis of the fly, and another fixed on the rod that is connected to the lever, by which means the fly makes one entire revolution, while the engine makes but one ſtroke; and thus the fly makes as many revolutions as the engine does ſtrokes: but we are inclined to give the preference to a ſimple crank with a fly of ſuch weight as ſhall have the deſired momentum with leſs velocity, ſimplicity being ever a deſideratum in the conſtruction of machinery.

It is related in the Encyclopædia Britannica that a Mr. Fitzgerald took out a patent for communicating a rotative motion from the ſteam-engine, and it may be ſo: but the firſt notice we ever had of a patent being obtained for that invention was about the year 1778, when a young man at Briſtol, Mr. Matthew Waſbrough, obtained letters patent for that purpoſe, and did apply it to his own works for turning lathes, &c. and alſo one at Southampton at Mr. Taylor's works, beſides two or three for grinding corn. However, this was previouſly to Mr. Watt's patent for that purpoſe; and, little as it was thought of at that period, it is now become of mighty conſequence to the kingdom at large.

We are glad to have an opportunity of preſenting the public with an improvement on the ſingle engine of Mr. Watt by Meſſrs. Hornblower, a patent for which was taken out by Mr. Jonathan Hornblower of Penryn, in the year 1781. We will give a ſhort account of this engine, not only that our readers may ſee what attempts have been made to carry on the progreſs of improvement, but that they may have an opportunity of comparing it with the account given of it in the Encyclopedia Britannica; as various opinions are ſtill entertained on the merit of that invention.

The intention of this improvement was to obtain a greater power by a complicated force of the ſteam than was ſuppoſed could be done by its action in a ſimple way; and, as it neceſſarily involves a novelty of conſtruction, we will give a repreſentation of the whole at fig. 8. where A and B are two cylinders of different capacities; and in this figure A is double the capacity of B: both of the cylinders are furniſhed with a piſton with their connection with the lever, as in the figure. The boiler is ſuppoſed to be placed on one ſide, having a pipe communicating it with the engine at G, and by occaſional communication through the branches by means of the four cocks or valves, the ſteam is ſent through the engine in the following manner: but here alſo we muſt deviate from the preciſe conſtruction to give a clear, an unequivocal idea of what paſſes in theſe two cylinders: therefore let A B fig. 9. be two cylinders, and let A be double the capacity of B, and let them be ſet one on the other each having a piſton, and both piſtons fixed on the ſame rod, and this rod to a lever having a weight at the other end; then if we ſuppoſe the upper piſton to be 1 inch diameter, the lower one will be = the ſquare root of 2 = 1·414 + of any determinate length, which we will ſay here 10 inches: and that we may not have our conceptions warped by complex notions, we will employ the preſſure of the atmoſphere in this experiment, inſtead of ſteam; and we will, for the ſake of round numbers, allow 12 lb. on every circular inch wherever the whole preſſure is employed.

The firſt thing, then, that is to be done is to let the lower piſton come very nearly in contact with the upper end of its own cylinder; that is, coming exceedingly near to *a a*, as in the figure: then both theſe piſtons working with very great niceneſs, being well oiled, let the atmoſpheric air enter between the two piſtons at the cock *x*, while there is a perfect vacuum in the larger cylinder under its piſton. If the whole of this little engine is at liberty, it will begin to make a ſtroke with 23 lbs. hanging on the outer end of the lever; becauſe there is 12 lbs. on the upper piſton, and 12 lbs. on the exceſs of area on the lower piſton. Then certainly it will balance a weight of 24 lbs. on the outer end of the lever; but next put a weight of 23 lbs. inſtead of 24, and we ſhall ſee that it will begin to make a ſtroke a little way downward: but it will ſoon ſtop, becauſe the atmoſpheric air between the two piſtons begins to be attenuated, and therefore its preſſure on the lower piſton will diminiſh; and this will be the caſe, gradually diminiſhing until it comes to the bottom, where its preſſure will be but half of what it was at the beginning; that is, 6 lbs. But let us now take notice of what has been going on with the ſmall piſton; and that is, that while the lower piſton has been deſcending with a decreaſing preſſure this piſton has had the whole preſſure of the atmoſphere upon it all the time; ſo that whereas it did equilibriate with 24 lbs. on the rod, it now ceaſes with the whole preſſure on the ſmaller piſton, and one half of the original preſſure on the exceſs of the larger piſton above the ſmall one, or one fourth of the preſſure of the whole lower piſton, making in the whole 18 lbs. at the termination of the ſtroke; and taking the ſum of the preſſures it will amount to 21.

Now let us ſee what is the true ſtate of the caſe with reſpect to Mr. Watt's application of the ſteam in what is called his expanſive engine, according to the repreſentation in fig. 1. Let A, fig. 10. repreſent the piſton of a cylinder equal to the capacity of the largeſt of the before mentioned = 1·414 + diameter, and 10 inches long, with its rod pendant to the lever as before; making uſe of air of the ſame denſity, for its effects muſt be the ſame, = 12 lbs. on the circular inch. Then, ſuppoſing an entire vacuum in the cylinder, let the piſton be brought as near the top of the cylinder as poſſible: being nicely oiled as before; let the air have acceſs to the upper ſide of the piſton, and it will ſupport a weight of 24 lbs. as before. Let this piſton deſcend half way down the cylinder, being ſupplied with air, and it ſtill ſupports 24 lbs. Now let the air-cock be ſhut, and no more air ſuffered to enter; and take off the 24 lb. weight and hang on a 12 lb. and they will bs in equilibrium at the termination of the ſtroke.

Here then we may compare the different reſults; for different they are, and will be, notwithſtanding the high authority to the contrary. If we obtain the accumulated preſſure by taking a mean of the extremes, we ſhall find Mr. Watt's application to be $\frac{24 + 24 + 12}{3} = 20$, leaving 12 lbs. at the termination of the ſtroke. T[illegible]pplication of the principle in the preſent inſtance, by taking the mean of the extremes, will be $\frac{24 + 18}{2} = 21$, leaving 18 at the termination of the ſtroke; which, in point of advantage in favour of the double cylinder, is as 3 : 2, a point of no ſmall magnitude in the practical application of this principle, and which ſeems to have been overlooked by all thoſe who have taken up the ſubject. Even the learned profeſſor himſelf has not taken into the account this diſtinguiſhing peculiarity, as he has only brought out the accumulated preſſure of both in a comparative view. Indeed the method he has adopted to inveſtigate this problem does not account for the ultimate expenditure of ſteam.

But we are warranted to preſent this to our readers in this popular and experimental manner by a very ſcrupulous attention to an engine erected in the vicinity of Bath ſome years ſince on this very principle, and under very diſadvantageous circumſtances. The engine had its two cylinders 19 and 24, with ſtrokes on each ſuitable to the occaſion, that is 6 feet and 8 feet reſpectively. The condenſing apparatus a very bad one; through a ſervile fear of infringement on a patent which infringed on every body; by which the greateſt degree of vacuum obtained was no more than 27 inches. The engine wrought 4 lifts of pumps to the depth of 576 feet, 4500 lbs. 14 ſtrokes in a minute, 6 feet each, with a cylinder 6 feet long, and 19 inches diameter, with a deal of inertia and friction in the rods and buckets; ſome of the latter of which were not more than 3½ inches diameter: and this it did under all theſe diſadvantages, with 70 lbs. of coal, *light coal*, per hour; which would have required a 24-inch cylinder of Mr. Watt's ſingle engine making a 6-foot ſtroke, with all the ſteam he could apply.

Two remarkable circumſtances preſented to ſhew the advantage of this application of the principle. The one was, that, in defiance of all order and regularity, the man who tended the engine, and pretended to underſtand it better than his maſter, would clandeſtinely detach the ſmaller cylinder from the other, and work only with the large one: but whenever detected, an idle excuſe only intervened between it and the reſtoration of things; and whereas the boiler (which was proverbially excellent) would ſcarcely by hard firing raiſe ſteam enough to keep the engine going: but no ſooner was the ſmall cylinder rod hung to the lever than the engine reſumed its wonted activity, and the ſteam would blow up the ſafety valve; and the boiler without great attention would boil over, nearly to emptying.

The next circumſtance is, that when the detent which kept the exhauſting-valve ſhut happened to miſs ſtays, as we may call it, the piſton would be balked, as it were, not being permitted to riſe the whole of the returning ſtroke; when it would, as by an inſtructive nature, come down again and again until the detent performed its office—a practical argument for the power of the engine at the termination of a ſtroke; but we believe nobody ſaw this effect with a jealous eye but Mr. Watt, and hence the production of Mr. Watt's ſecond patent.

Here, then, was an engine working with the effect of 16 lbs. on the ſquare inch of the piſton; for all the ſteam that was employed in producing this effect, was no more than what ſupplied the ſmaller cylinder. The various diſputes and contentions about the ſuperiority of Mr. Watt's engines comparing the effects with this engine, ſubſiſted only on account of the difficulty of making a fair comparative experiment which, unleſs they could be done with engines on the ſame circumſtances, could not be done at all, and on account of the nature of drawing the water in different mines, no circumſtances could be found to juſtify this compariſon.

We are told in the Supplement to the Encyclopedia Britannica, that the *form* of the engine mentioned in the 766th page of the body of that work was put in practice about the year 1775, and that this is mentioned, "becauſe we have been told Mr. Hornblower puts in a prior claim to the invention;" and then adds, "We do not think that Mr. Hornblower erected any of his engines before 1782; and as Mr. Hornblower was, we believe, working with Boulton and Watt before that time, we think it fully more than probable that he has in this reſpect profited by the inſtruction of ſuch intelligent employers." We forbear to deſcant on the mechanical intelligence of the employers, at that period; but we are authoriſed to ſtate this as an unjuſtifiable libel on Mr. Hornblower. In the firſt place, Mr. Hornblower never worked with Boulton and Watt; and ſuppoſing Mr. Hornblower never put up any of his engines until 1782, are we to infer from thence that the principle was not thought on, nor any experiments inſtituted to aſcertain the beſt mode of applying that principle? We have likewiſe to ſtate that Mr. Hornblower took up the ſubject of his engine early in the year 1776, if not before, and continued it until he made a large working model whoſe cylinders were 11 and 14 inches diameter, and that a drawing of this engine was ſent to the editor of the Encyclopedia Britannica, with a proper deſcription and references accompanying it; that Dr. Gleig returned the drawing to Mr. Hornblower with a very polite letter of acknowledgment for the favour done to his work, adding, that it would appear with Dr. Robiſon's marks of peculiar approbation, who was to undertake the writing on that article, &c. &c. and that when theſe marks of high approbation were publiſhed, it was to ſet forth how ingeniouſly Mr. Hornblower had contrived the framing of the lever, his valves, and ſtuffing-box, but that the engine was in no reſpect preferable to Mr. Watt's with a ſingle cylinder, but in ſome accounts very much inferior! That Mr. Hornblower addreſſed a letter of ſurpriſe and reſentment to Dr. Robiſon at ſuch an indirect inſtance of behaviour, which probably brought the prejudices of the candid philoſopher into view whenever he had occaſion to refer to Mr. Hornblower's name. We have to ſtate further, that we do not believe that Mr. Watt's uſe of the expanſion-valve had ever been put in practice until *long after* Mr. Hornblower projected his deſign of the double engine. However, we are certain that this engine brought forth Mr. Watt's ſecond patent for the moſt arrant ſyſtem of abſurdities that ever came into view in the mechanical world, to avail himſelf of the means of continuing the preſſure on his piſton with as much effect as he ſaw inherent in the principle on which Mr. Hornblower's engine was conſtructed; but we have never ſeen one inſtance in which any of the prepoſterous methods ſanctioned by the patent referred to were put in practice.

We are now to take notice of another engine of Mr. Hornblower's, for which letters patent have been lately granted, having a rotary motion within itſelf by the immediate action of ſteam on 4 revolving piſtons. We confeſs our inability to do juſtice to this moſt ſimple ſteam-engine we ever ſaw, ſo novel in its conſtruction, yet ſimple in its operation. The piſtons juſt mentioned are four vanes like thoſe of a ſmoke-jack, though not of thin iron, but of ſome conſiderable thickneſs, ſufficient to form a groove to hold ſome ſtuffing for the purpoſe of being tight in their action. They are mounted on an arbor, which has a hollow nave in the middle. Into this nave the tails of the vanes are inſerted, and each oppoſite vane is affected alike by having a ſteady connection with each others: for inſtance, if we ſhould alter the angle of one of the vanes with the arbor, the oppoſite one will be altered too, and they are not ſet in the ſame plane, but at right angles to the plane of each other; ſo that, if we (in retaining the notion of the vanes of a ſmoke-jack) conceive theſe vanes to be held in a vertical poſition as the ſails of a windmill, when one vane is flatly oppoſed to the wind, the oppoſite vane will preſent its *edge* to the wind, and this they are conſtantly doing in their rotation on their common arbor, ſo [illegible] the ſteam acts againſt the vane on its face in propelling it [illegible] and this it does for about $\frac{1}{4}$ of a circle or 90 degrees in the [illegible] where it is deſtined to act; and as ſoon as it has gone through the quarter of the circle, it inſtantly turns its edge to the ſteam, while at the ſame inſtant another vane has entered the working part of the box, and the rotation proceeds without interruption.

It muſt be obſerved, that though the engine has the power of preſenting the edge of the vanes to the ſteam in returning to its place of active force, that yet there muſt be ſome power loſt according to the re-action on the thickneſs of the edge, and this loſs of power is greateſt only in ſmall engines; but in a ſyſtem of vanes extending 5 or 6 feet, moving at the rate of 30 revolutions in a minute, there muſt be a great accumulation of force; and that this accumulation is in favour of the principle of the engine, where the velocity of the power may be of any determinate ratio to the velocity of the weight, according to the exiſting circumſtances. It muſt alſo be underſtood that this engine is to be furniſhed with condenſer and diſcharging-pump, according to the new mode of condenſation eſtabliſhed by Mr. Watt; but Mr. Hornblower has (*as we think*) an improved method of diſcharging, whereby he takes all the air from the condenſer in a moſt perfect manner. This apparatus is to be connected to one end of the arbor which carries the vanes or piſtons, while the other end is connected with the work.

Fig. 11. is the plan or horizontal ſection of the engine where AA is the exterior box or caſing; BC two of the vanes; C preſenting its whole ſurface of one, and B ſhewing the edge of the other; *pppp* forms an entire partition; ſo that all the communication between the upper and nether parts of the box are at BC; D is the nave through which the vanes are connected, and OO is the arbor. Fig. 12. ſhews a vertical ſection through the ſame line; C and B ſhew the ſame vanes in the ſame poſition as before. The nave in the middle is open to ſhew how the two vanes are connected. Another two being connected in the ſame manner, will have liberty to turn a quarter round without obſtruction by the crooked part of the communicating axis; this is the ſteam-pipe, and the exhauſting-pipe may be placed any-where above the partition*.

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* The author, at the ſame time that he entertains the greateſt reſpect for the practical talents of the ingenious contributor of this deſcriptive hiſtory, and of the inventor of the ſteam-wheel juſt deſcribed, ſtill thinks it right to ſtate his apprehenſions that it may not be found in practice to poſſeſs all the advantages which at firſt view one would be inclined to aſcribe to it. Is there not ſome ground to fear that in this contrivance, beſides the force loſt by the action of the ſteam upon the edges of the vanes, there will be a conſiderable loſs ariſing from the greater friction attending its operations than thoſe of a common ſteam-engine? In this ſteam-wheel there will be a great quantity of rough ſurface (that of the ſtuffing) expoſed to frequent contact, and conſequent reſiſtance to the moving from the fixed parts. Beſides, as the ſtuffed parts are here of great extent with regard to the magnitude of the machinery, and exhibit rapid variations of ſhape, they may, when brought into conſtant work, be found difficult to keep in order. Whether the diſadvantages which may ariſe from theſe cauſes, may be as great as thoſe that are known to attend the other engines, and particularly whether they will be equivalent to the force abſorbed by giving a new impulſe to the whole maſs of matter ſubject to the reciprocating motion at every change in the direction, can only be ſatisfactorily aſcertained by ſubjecting both engines to comparative work in as nearly the ſame circumſtances as the difference in conſtruction will admit. But if by further attention to this ingenious

It would be employing time to very little purpoſe to enumerate the various projects which are ſet up to rival Mr. Watt's engine; and if we had not ſeen that the moſt palpable abſurdities are not without patronage, not in engineering only, but in concerns of greater or leſs importance, we ſhould not be able to account for the preference ſhewn to ſome of as immeritorious productions as have peſtered the world at any age; but the misfortune in our country is, that we all are great mechanics and ſage politicians, and while one engine is condemned on account of its complex conſtruction, however eſſential, others are celebrated for their ſimplicity, however abſurd.

We muſt however redeem from this charge an engine invented by Mr. Edmund Cartwright, which has as much merit as can poſſibly be attributed to a gentleman engaged in the purſuit of mechanical ſtudies for his own amuſement. Mr. Cartwright has two very important deſiderata in view, a tight piſton and a vacuous condenſer; that is to ſay, a condenſer from which the atmoſpheric air is excluded: to accompliſh which it is made of as thin copper as it will admit, expoſing a large ſurface to the water, then the ſteam internally comes in contact with the metal of the ſame temperature, and hence the condenſation. We wiſh it were poſſible to put this grand deſign into a decided effect: but from ſome particulars we have obſerved in the doctrine of condenſation, no method yet explored will obtain ſo rapid a condenſation as actual contact with the water; we do not account for this by any chemical affinity, but by the expoſure of ſurface; for the experiment has been tried to our ſatisfaction, that when the jet was not in a diſperſive ſtate, the condenſation was tardy and inactive; and if it were poſſible to diſperſe the jet into a miſt, we ſhould obtain the moſt prompt condenſation poſſible.

But ſtill we do not conceive an inſtantaneous condenſation is abſolutely neceſſary; for if it is performed during the time of the required ſtroke, that is all which is wanted. We cannot ſay whether Mr. Cartwright has ſucceeded ultimately to this point or not.

We remember to have ſeen preparations for an apparatus for this mode of condenſing ſome years ſince, by an aſſemblage of taper pipes of about a quarter of an inch diameter, expoſing a ſurface of between 90 and 100 feet to a 20-inch cylinder; but

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contrivance, Mr. Hornblower ſhould be able to work his ſteam-wheel in a manner free from any material draw-back upon the advantage ariſing from its conſtant rotatory motion in one direction, it would then undoubtedly be ſuperior to any ſteam-engine of which we have ever heard, or that has probably been yet invented.

an accident from a rude hand prevented its application for that time, and we do not think it was ever reſumed.

The packing of Mr. Cartwright's piſton is compoſed of a ſeries of ſegments of braſs, the arches of which conform exactly to the circumference of the cylinder; theſe are to be laid on the verge of the piſton ſo as to make one entire diſk, then another and another ſtratum ſuper ſtratum until the deſigned thickneſs is acquired: then to keep theſe ſegments in conſtant tendency to the place of action, there are a ſet of ſprings very nicely contrived to act on the concave edge, which, no doubt, will keep them to their work; but the difficulty is how to preſerve the fit at the junctures: it is impoſſible for the ſegment of a ſmall circle to become the ſegment of a larger circle*. But we do not ſuppoſe Mr. Cartwright to have intended this metallic packing to compenſate the irregular figure of the ſteam-veſſel, for it is impoſſible; beſide, Mr. Cartwright's notions of accuracy would never ſuffer him to admit a ſteam-veſſel to his engine which was not a perfect cylinder; in which caſe theſe ſegments may have but little wear, though, if they were of metal in any degree ſofter than the cylinder, the duſt which will find its way there, would wear away the cylinder ſo as to be ſenſibly detrimental: added, that this packing could never apply to a double engine. It, however, ſerves as a very elegant ſpecimen of the inventor's inclination to accurate working.

Since the above was written, we have ſeen an engine of Mr. Cartwright's at a tan-yard near Horſley-Down, which gives great ſatisfaction to the proprietor. The piſton, by the account of the tender of the engine, has not even been looked at for many months, nor has he any indications that it will be neceſſary for many more. This account receives ſtrong confirmation by the appearance of the quantity of condenſed ſteam which is diſcharged from the engine every ſtroke, which, as it is not effected in the common way (by injection), can be very exactly eſtimated. Its conſtruction is very ſimple, and it performs its operations very ſmoothly and effectually†.

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* Admitting that theſe ſegments wear away on the outer arches, the inner arches muſt recede from the centre, and therefore will be one continued deduction from the entire circle.

† Mr. Cartwright's contrivance for preſerving the parallel motion of the piſton-rod, at the ſame time that it communicates the rotatory motion to the fly, is very ingenious, and is therefore ſhewn in plate XXXV. fig. 3. where P is the top of the piſton-rod, upon which is ſcrewed a tranſverſe bar B: to the ends of this bar, at equal diſtances from the top of the piſton-rod, are attached the two equal connecting rods H, H, which as the piſton riſes and falls turn the cranks and the two equal wheels W, W; theſe two equal wheels work into each other, and one of them drives the pinion C upon the ſame axis as the fly-wheel O; thus communicating the rotatory motion to the other parts of the machinery. AUTHOR.

To conclude this ſubject: Mr. Watt's engine, as it now ſtands, is the work of ſix-and-thirty years, and we may hold it as complete in its kind as it poſſibly can be. It has exerciſed all the ingenuity of the inventor, beſide frequent acceſſions from the ingenuity of other men: various pretenſions and conceits no doubt will abound to rival its excellency, and time only, the arbiter in human affairs, will determine their fate. We would rather ſee a laudable competition prevail to ſimplify its parts, without affecting the principle, either by reducing their number, or by diſpenſing with their coſtly finiſh, or perhaps both, that it may come within the compaſs of the middle ranks as well as of the more opulent: and the man who ſets the example will deſerve well of his country.

II. A communication from Mr. Farey, junior.

Pl. XXXI. fig. 1. repreſents a Steam-Engine, erected in 1802, by Meſſrs. *Murray* and *Wood* of Leeds, for *Francis Brewin*, eſq. at his tan-yard in Willow Walk, Bermondſey; and fig. 2. repreſents ſome parts thereof on a larger ſcale: AA is the ſhaft for conveying the power of the engine to work a bark-mill and ſeveral pumps. The ſteam from the boiler enters through the pipe B into the aſſemblage of pipes, technically termed *noſsels*, or *value-boxes*, repreſented ſeparately in fig. 2, which contain the valves for diſtributing the ſteam at proper intervals into the cylinder CC, and letting the ſame off again to the condenſer M. The cylinder CC, which is caſed with wood to keep in the heat, has a ſolid piſton moving in it, whoſe poliſhed *piſton-rod* D paſſes through a ſtuffing-box; the upright motion of this rod is converted into a rotary one by the following contrivance: the circular rim E, three feet diameter, with ſeventy-two teeth on the inſide, is firmly fixed and ſuſpended from the floor, by two caſt-iron pillars FF and braces LL; the ſmall wheel G, of eighteen inches diameter and thirty-ſix teeth, is made to revolve within-ſide of the rim, ſo as always to touch the teeth by a pin (the end of which is repreſented in the centre of the wheel G), firmly fixed on the wheel H, parallel to its axis AA, with which it always moves; and nine inches from its centre, on the circumference of the wheel G, is a bolt I, ſcrewed on perpendicular to its plane, in ſuch a place, that when the wheel G is at the bottom of the rim E, the bolt is on the loweſt tooth; and when the ſmall wheel is at the top of the rim, it is on the higheſt: to this bolt the piſton-rod D and the air-pump-rod K are attached, and the tops of theſe rods, by moving up and down in right lines, paſſing through the axis of the wheel H, will communicate a rotatory motion to that wheel, and all on the ſame ſhaft. (See the article PARALLEL *Motion*).

The wheel *a*, on the axis AA of the fly-wheel NN, communicates its motion by the wheels ſhewn in fig. 2, to the wheel *b*; which wheels are ſo contrived, that one revolution of the fly will produce one of the wheel *b*, on whoſe axis are two eccentric wheels *c* and *d*, which alternately raiſe the rods *e* and *f*, for opening the valves contained in the ſhort cylinders or valve-boxes *g g* and *h h*: each of theſe boxes has three diviſions; the upper diviſion of the upper box contains a valve 1, called the *upper ſteam-valve*; its uſe is to admit ſteam from the boiler through the pipe B, into the middle diviſion which communicates with the cylinder; in this box is a valve 2 (which is moved by a rod paſſing through the rod of the other valve 1), called the *upper condenſing-valve* (or *exhauſting-valve*); it is for opening a paſſage from the top of the cylinder to the condenſer by the pipe *q*. In the ſame manner, the upper valve 3 of the lower box is called the *lower ſteam-valve*, and is for admitting ſteam into the lower part of the cylinder by means of the pipe *r*; the valve 4 is for connecting the bottom of the cylinder with the condenſer, and is therefore called the *lower condenſing-valve*. The rod *f* connects at its top with the *upper condenſing-valve* (2), and the *lower ſteam-valve* (3) at its bottom; it will therefore, when it is lifted up by the eccentric wheel *d*, open thoſe valves, and by cauſing a vacuum above, and a preſſure of ſteam beneath, the piſton, force it upwards, and move the machinery: alſo the rod *e*, connecting with the *upper ſteam-valve* 1 at its top, and the *lower condenſing-valve* 4 at its bottom, being lifted up by the eccentric wheel *c*, will cauſe the piſton to deſcend; but this will not be the caſe, unleſs one rod is permitted to deſcend by its own weight, as the other is lifted, otherwiſe the ſteam will leave free paſſage from the boiler to the condenſer, which operation is called *blowing through*.

The condenſer M is a cylindric veſſel, into which is admitted a ſmall jet of cold water, by the cock *l*, called the injection-cock: the bottom of the condenſer communicates by a ſhort pipe O (which pipe contains a valve ſhutting towards the condenſer), with the *air-pump* P, four inches diameter and three feet ſtroke; the piſton of the air-pump has a valve in it, and is moved by the rod K, as before deſcribed; the air-pump's office is to extract the water of the condenſed ſteam, injection, &c. from the condenſer, and keep the vacuum perfect. The air-pump and condenſer muſt be in a well or ciſtern of cold water.

To work this engine, the ſteam muſt be made of ſufficient elaſticity to ruſh forcibly out of the boiler when permitted;

draw the handles *n* and *o* apart from each other, which acting as levers againſt the ſtubs on the rods *e* and *f*, will raiſe them up in a ſmall degree, and open all the valves at once; and the ſteam by *blowing through*, will expel the water, air, &c. which may have filled the cylinder and condenſer, at a valve ſhutting outwards in the condenſer for that purpoſe. When it is thought that the air, &c. is all driven out, one or other of the handles muſt be dropped (according to the poſition of the wheel G); the injection cock *l* is then opened by its handle *p*, which ſuddenly cooling the ſteam, reduces it to the bulk it formerly poſſeſſed in the boiler, and forms a vacuum in the condenſer; the ſteam from the cylinder which ruſhes in to reſtore the equilibrium is condenſed as it goes, and almoſt inſtantaneouſly a nearly perfect vacuum is formed on one ſide of the piſton; and the ſteam from the boiler preſſing on the other, deſtroys the equilibrium on it, and puts the engine in motion. When the piſton is at the top of its ſtroke by the arrangement of the wheels in fig. 2, the eccentric wheel *c* will lift the rod *e* (at the time the rod *f* is permitted to deſcend by its weight), and cauſe the piſton to deſcend; and when at the bottom the rod *f* will be lifted, and *e* will fall, which forces it upwards again.

To ſtop the engine, nothing is neceſſary but to lift up both the handles and ſhut the injection-cock (which ſhould always be ſhut when the engine is not at work), to prevent the condenſer from filling with water; and as ſoon as the momentum of the fly-wheel is ſpent, the motion of the engine will ceaſe; it might alſo be ſtopped by only cutting off the injection, which would, after a conſiderable number of ſtrokes, render the vacuum ſo imperfect as to deſtroy its power.

The cylinder of this engine is twelve inches diameter, and has a three-feet ſtroke; its power is computed at four horſes, it makes about fifteen ſtrokes per minute, and burns about nine buſhels of coals in fourteen hours, being the uſual period of working.

III. M. *Bettancourt*, whoſe curious and valuable experiments on the expanſive force of ſteam are mentioned in the introductory part of this volume, was employed by the court of Spain to make a collection of reſearches and of models for the perfection of hydraulics: when in England he took occaſion (according to M. Prony) to viſit the ſteam-engines *(machines à feu)* of Meſſrs. Boulton and Watt. He ſaw, in part, the exterior conſtruction and operation of thoſe machines; but the interior mechaniſm was ſo concealed, that M. Bettancourt could only gueſs at the nature of the conſtruction. He obſerved that the chains were ſuppreſſed, which are uſually put at the extremities of the great beam; and ſeparating walls, &c. prevented him from examining all even of the exterior parts, ſo as thoroughly to underſtand their correſpondence and complete effect: he concluded, notwithſtanding, from his obſervations, that the piſton of the cylinder was urged with the ſame effort, both in its deſcent and its aſcent; and this, in fact, was diſcovering the double effect which conſtitutes eſſentially the chief improvement made in theſe machines by Meſſrs. Boulton and Watt.

M. Bettancourt ſoon after deviſed ſome ſteam-engines of double effect; one of which being very ſimple and ingenious, may here be deſcribed, at leaſt all which is peculiar to it. See fig. 3. pl. XXXI. The ſteam coming in the ordinary way from the boiler, which is omitted to render the deſign more ſimple, paſſes through the tube *b*, and introduces itſelf by the aperture *v* into the ſpace of which the circle *ee'* repreſents the profile or vertical ſection. This chamber *ee'* has, beſides the orifice *v*, two others, the one placed by the ſide of the canal *d*, to communicate by means of that canal with the ſuperior part B of the cylinder BB'; the other placed below at *v'*, and communicates by means of the tube or canal *v' d'* with the inferior part B' of the cylinder, of which the piſton is repreſented in X. The ſpace, or circular chamber *e'' e'''*, communicates in a ſimilar manner with the upper and lower parts of the cylinder, by means of the tube *v'' d*, and the canal *d'*. Moreover, this chamber *e'' e'''* communicates by means of the orifice *v'''* with the chamber *ff'*, where the valve *j* is found adapted to the aperture through which iſſues the water of injection deſtined to condenſe the vapour: this valve is always open, except when we would ſtop the machine; but it may approach the orifice more or leſs, according to the velocity which we would give to the piſton. The outlets *v* and *v'''* are, in like manner, always open.

The orifices *v'*, *v''*, and thoſe which eſtabliſh the communication with the cylinder by means of the canals *d* and *d'*, are cloſed alternately by the valves *g h*, or *g' h'* of a particular kind. Fig. 3. no. 2. repreſents the profile of either of theſe valves. The part *g h* curved into the arc of a circle of the ſame radius as that of the vertical ſections *ee'*, *e'' e'''*, and turning upon an axis placed at the centre *o*, may in its revolution cloſe any aperture whatever placed upon the circumference of thoſe ſections.

This being underſtood, ſuppoſe things in the ſtate repreſented in fig. 3. no. 1. and the vacuum eſtabliſhed in the part of the cylinder above the piſton. The ſteam entering by the orifice *v*, finds the canal *d* cloſed, paſſes through the tube

$v'd'$, but cannot introduce itſelf into the chamber $e'\,e''$ becauſe of the valve $g'h'$; it therefore enters wholly into the lower part B' of the cylinder. Hence it acts upon the piſton X, with all the energy of which it is capable: the piſton puſhes the great beam by means of the piſton-rod XK, and the oppoſite part of that beam acts with a like effort upon the rod or bar deſtined to give the rotatory motion to the fly. The piſton X having thus arrived at the higheſt point of its courſe, the valve $g'h'$ makes a part of a rotation, ſo as to cloſe the orifice v'', and open the canal d'; in the ſame time the valve gh makes part of a revolution likewiſe, to cloſe the aperture v' and open the canal d. The aqueous gas continuing to enter at v, which is conſtantly open, finds the orifice v' cloſed, penetrates into the canal d, and not having any paſſage through the orifice v'', goes entirely into the upper part of the cylinder: during this time, the ſteam which was in B' is expelled through d', penetrates into v''', which is always open, and becomes condenſed about the valve j. By theſe means the ſteam which enters B, acting with all its energy upon the piſton X, makes it deſcend, and produces, by deſcending, equal effects to thoſe it cauſed when aſcending. The piſton, then, having arrived at the loweſt point of its courſe, the valve gh which cloſed the orifice v', and the valve $g'h'$, which cloſed the orifice v'', return both to their primitive ſituation; and ſo on throughout.

The extent of the ſtroke of the piſton muſt manifeſtly be ſuch that the apertures of the canals at d, and d', placed in the ſide of the cylinder, are never ſtopped by the piſton.

It is almoſt needleſs to ſay, that the interior mechaniſm relative to the valves gh, $g'h'$, may be moved by various contrivances, each depending upon the alternating motion of the piſton: ſo that no other agents will be required diſtinct from the machinery, than what are wanted for keeping up the fire.

IV. Before we entirely quit the ſubject of ſteam-engines, we ſhall preſent the reader with ſome account of the late improvements in their conſtruction, &c. by Mr. *Arthur Woolf*.

Mr. Woolf founds his improvements on a very important diſcovery which he has made reſpecting the expanſibility of ſteam when increaſed in temperature beyond the boiling point, or 212° of Fahrenheit's thermometer. It has been known for ſome time—and for this diſcovery the world is indebted to Mr. Watt, the principal improver of the ſteam-engine—that ſteam acting with the expanſive force of four pounds the ſquare inch against a ſafety-valve expoſed to the atmoſphere, is capable of expanding itſelf to four times the volume it then occupies, and ſtill to be equal to the preſſure of the atmoſphere. Mr. Woolf has diſcovered that, in like manner, ſteam of the force of five pounds the ſquare inch can expand itſelf to five times its volume; that maſſes or quantities of ſteam of the like expanſive force of ſix, ſeven, eight, nine, or ten pounds the ſquare inch, can expand to ſix, ſeven, eight, nine, or ten times their volumes, and ſtill be reſpectively equal to the atmoſphere, or capable of producing a ſufficient action againſt the piſton of a ſteam-engine to cauſe the ſame to riſe in the old engine (with a counterpoiſe) of Newcomen, or to be carried into the vacuous part of the cylinder in the improved engines firſt brought into effect by Meſſrs. Boulton and Watt; that this ratio is progreſſive, and nearly if not entirely uniform, ſo that ſteam of the expanſive force of twenty, thirty, forty, or fifty pounds the ſquare inch of a common ſafety-valve will expand itſelf to twenty, thirty, forty, or fifty times its volume; and that, generally, as to all the intermediate or higher degrees of elaſtic force, the number of times which ſteam of any temperature and force can expand itſelf is nearly the ſame as the number of pounds it is able to ſuſtain on a ſquare inch expoſed to the common atmoſpheric preſſure; provided always that the ſpace, place, or veſſel, in which it is allowed to expand itſelf, be of the ſame temperature as that of the ſteam before it be allowed room to expand.

Reſpecting the different degrees of temperature required to bring ſteam to, and maintain it at, different expanſive forces above the weight of the atmoſphere, Mr. Woolf has found, by actual experiment, ſetting out from the boiling point of water, or 212°, at which degree ſteam of water is only equal to the preſſure of the atmoſphere, that in order to give it an increaſed elaſtic force equal to five pounds the ſquare inch, the temperature muſt be raiſed to about 227½°, when it will have acquired a power to expand itſelf to five times its volume, ſtill be equal in preſſure to the atmoſphere, and capable of being applied as ſuch in the working of ſteam-engines, according to his invention; and with regard to various other preſſures, temperatures, and expanſive forces of ſteam, the ſame are ſhown in the following table:

Table of the relative preſſure per ſquare inch, temperatures, and expanſibility of ſteam at degrees of heat above the boiling point of water, beginning with the temperature of ſteam of an elaſtic force equal to five pounds per ſquare inch, and extending to ſteam able to ſuſtain forty pounds on the ſquare inch.

	Pounds per square Inch.		Degrees of heat.		Expanſibility.	
Steam of an elaſtic force predominating over the preſſure of the atmoſphere upon a ſafety-valve.	5	requires to be maintained by a temperature equal to about	227½	and at theſe reſpective degrees of heat, ſteam can expand itſelf to about	5	times its volume, and continue equal in elaſticity to the preſſure of the atmoſphere
	6		230¼		6	
	7		232¾		7	
	8		235½		8	
	9		237½		9	
	10		239½		10	
	15		250½		15	
	20		259½		20	
	25		267		25	
	30		273		30	
	35		278		35	
	40		282		40	

So in like manner, by ſmall additions of temperature, an expanſive power may be given to ſteam to enable it to expand to fifty, ſixty, ſeventy, eighty, ninety, one hundred, two hundred, three hundred, or more times its volume, without any limitation but what is impoſed by the frangible nature of every material of which boilers and the other parts of ſteam-engines have been or can be made; and prudence dictates that the expanſive force ſhould never be carried to the utmoſt the materials can bear, but rather be kept conſiderably within that limit.

Having thus briefly explained the nature of Mr. Woolf's diſcovery, we ſhall proceed to give a deſcription of his improvements grounded upon them; and for which he has obtained the uſual ſecurity of a patent. Mr. Woolf in his ſpecification ſtates, that in deſcribing his invention he has found it neceſſary to mention the entire ſteam-engine and its parts, to which, as an invention well known, he neither can nor does aſſert any excluſive claim: he obſerves, however, that from the nature of his aforeſaid diſcovery, and its application, there can be no difficulty in diſtinguiſhing his ſaid improvements from the improved engine (of Mr. Watt) as to its other common and well-known parts, and then gives the following account of an engine embracing his new improvements.

" If the engine be conſtructed originally with the intention of adopting my ſaid improvement, it ought to have two ſteam-veſſels of different dimenſions, according to the temperature or the expanſive force determined to be communicated to the ſteam made uſe of in working the engine; for the ſmaller ſteam-veſſel or cylinder muſt be a meaſure for the larger. For example, if ſteam of forty pounds the ſquare inch is fixed on, then the ſmaller ſteam-veſſel ſhould be at leaſt one-fortieth part the contents of the larger one; each ſteam-veſſel ſhould be furniſhed with a piſton, and the ſmaller cylinder ſhould have a communication both at its top and bottom (top and bottom being here employed merely as relative terms, for the cylinders may be worked in a horizontal or any other required poſition, as well as vertical), the ſmall cylinder, I ſay, ſhould have a communication both at its top and bottom with the boiler which ſupplies the ſteam; which communications, by means of cocks or valves of any conſtruction adapted to the uſe, are to be alternately opened and ſhut during the working of the engine. The top of the ſmall cylinder ſhould have a communication with the bottom of the larger cylinder, and the bottom of the ſmaller one with the top of the larger, with proper means to open and ſhut theſe alternately by cocks, valves, or any other well-known contrivance. And both the top and bottom of the larger cylinder or ſteam-veſſel ſhould, while the engine is at work, communicate alternately with a condenſing veſſel, into which a jet of water is admitted to haſten the condenſation, or the condenſing veſſel may be cooled by any other means calculated to produce that effect. Things being thus arranged, when the engine is at work, ſteam of high temperature is admitted from the boiler to act by its elaſtic force on one ſide of the ſmaller piſton, while the ſteam which had laſt moved it has a communication with the larger ſteam-veſſel or cylinder, where it follows the larger piſton now moving towards that end of its cylinder which is open to the condenſing veſſel. Let both piſtons end their ſtroke at one time, and let us now ſuppoſe them both at the top of their reſpective cylinders, ready to deſcend; then the ſteam of forty pounds the ſquare inch entering above the ſmaller piſton will carry it downwards, while the ſteam below it, inſtead of being allowed to eſcape into the atmoſphere or applied to any other purpoſe, will paſs into the larger cylinder above its piſton, which will take its downward ſtroke at the ſame time that the piſton of the ſmall cylinder is doing the ſmall thing; and while this goes on, the ſteam which laſt filled the larger cylinder, in the upward ſtroke of the engine, will be paſſing into the condenſer to be condenſed during the downward ſtroke. When the piſtons in the ſmaller and larger cylinder have thus been made to deſcend to the bottom of their reſpective cylinders, then the ſteam from the boiler is to be ſhut off from the top and admitted to the bottom of the ſmaller cylinder, and the communication between the bottom of the ſmaller and the top of the larger cylinder is alſo to be cut off, and the communication to be opened between the top of the ſmaller and the bottom of the larger cylinder; the ſteam, which in the downward ſtroke of the engine filled the larger cylinder, being now open to the condenſer, and the communication between the bottom of the larger cylinder and the condenſer ſhut off; and ſo on alternately, admitting the ſteam to the different ſides of the ſmaller piſton, while the ſteam laſt admitted into the ſmaller cylinder paſſes alternately to the different ſides of the larger piſton in the larger cylinder, the top and bottom of which are made to communicate alternately with the condenſer.

" In an engine working with the improvements which have been juſt deſcribed, while the ſteam is admitted to one ſide of the piſton in the ſmaller cylinder, the ſteam on the other ſide has room made for its admiſſion into the larger cylinder, on one ſide of its piſton, by the condenſation taking place on the other ſide of the large piſton which is open to the condenſer; and that waſte of ſteam which takes place in engines worked only by the expanſive force of ſteam, from ſteam paſſing the piſton, is prevented; for all ſteam that paſſes the piſton in the ſmaller cylinder is received into the larger.

" In ſuch an engine, where it may be more convenient for any particular purpoſe, the arrangement may be altered, and the top of the ſmaller made to communicate with the top of the larger, and the bottom of the ſmaller with the bottom of the larger cylinder; in which caſe the only difference will be, that when the piſton in the ſmaller cylinder deſcends, that in the larger will aſcend; and while the other deſcends, the former will aſcend; which for ſome particular purpoſes may be more convenient than the arrangement before deſcribed."

Mr. Woolf, in his ſpecification, deſcribes various other modifications of his invention; and points out means for applying his improvements, before ſtated, to the working of ſteam-engines already conſtructed, and in uſe; that is, to the working of engines with one ſteam-veſſel only, without taking advantage of the expanſive force of the ſteam on a piſton in another cylinder. Suffice it to ſay, that proper means being employed to keep the ſteam-veſſel or working cylinder at the required temperature, the ſteam is admitted into it in quantities proportioned to its expanſive power: for example, if the ſteam be of a force equal to forty pounds the ſquare inch, the throatle-valve is ſo adjuſted as to admit into the working cylinder a quantity of ſteam equal to only one-fortieth part of its capacity, which ſteam expands as it enters, ſo as to fill completely the whole cylinder.

In this firſt improvement of Mr. Woolf, though the ſaving of fuel might be carried to a conſiderable length, and, with an engine erected by Meſſrs. Murray and Cay of Leeds, has actually been proved to be more than one-half of the whole quantity employed in a well-conſtructed double engine of the ſame power, it was ſtill neceſſarily limited by the ſtrength of materials; for in the employment of high ſteam, there muſt always be ſome danger of an exploſion. Mr. Woolf, however, by a happy thought, has completely obviated every danger of this kind, and can now take the full advantage of the expanſive principle without the leaſt danger whatever. This he effects by throwing into common ſteam the additional temperature neceſſary for its high expanſion, after the ſteam is admitted into the working cylinder, which is heated by means adequate to the end intended to be obtained; and the advantage which he thus gains, he effectually ſecures by a moſt ingenious improvement in the piſton. It may be eaſily conceived that ſteam of ſuch high rarity as Mr. Woolf employs, could not be made fully effective with the piſton in common uſe; for in proportion to its rarity, ſo muſt be the facility with which a portion of it would eſcape, and paſs by the ſide of the piſton to the vacuous part of the cylinder: but Mr. Woolf's contrivance, which conſiſts in employing upon the piſton a column of mercury or other metals in a ſtate of fuſion of an altitude equal to the preſſure of the ſteam, ſeems perfectly adapted to prevent the loſs of even the ſmalleſt portion of the ſteam.

Beſides theſe improvements on the common ſteam-engine, he has alſo found means to apply the ſame principles to the old engine, known by the name of Savary's, in ſuch a way as to render the ſame a powerful and economical engine for a great variety of purpoſes.

Such is the outline of Mr. Woolf's new improvements on this moſt uſeful engine: but, for the general information of practical engineers, we ſhall here ſubjoin a more technical deſcription in Mr. Woolf's own words, extracted from his ſpecification of his ſecond patent.

"I have found out and invented a contrivance, by which the temperature of the ſteam-veſſel or working-cylinder of a ſteam-engine, or of the ſteam-veſſels or cylinders where more than one are uſed, may be raiſed to any required temperature, without admitting ſteam from the boiler into any ſurrounding receptacle, whether known by the name of a ſteam-caſe, or by any other denomination. That is to ſay, inſtead of admitting ſteam of a high temperature into ſuch receptacle or ſteam-caſe, which is always attended with a riſk of exploſion proportioned to the elaſticity of the ſteam employed, I put into the ſaid ſurrounding receptacle, or caſe, oil or the fat of animals, or wax or other ſubſtances capable of being melted by a lower temperature than the heat intended to be employed, and of bearing that heat without being converted into vapour: or I put into the ſaid caſe or caſes mercury or mixtures of metals, as of tin, biſmuth, and lead, capable of being kept in a ſtate of fuſion in a lower temperature than that intended to be employed in working the ſteam-engine: and I ſo form the ſurrounding caſe or caſes as to make it or them admit the aforeſaid oil, or other ſubſtance employed, to come into contact not only with the ſides of the ſteam-veſſel or veſſels, or working cylinder or cylinders, but alſo with the bottom and top of the ſame, ſo that the whole may be as much as poſſible maintained at one uniform temperature; and this temperature I keep up by a fire immediately under or round the caſe or caſes that contain the aforeſaid oil or other ſubſtance, or by connecting the ſaid caſe or caſes with a ſeparate veſſel or veſſels, kept at a proper temperature, filled with the oil or other ſubſtance made uſe of as aforeſaid. In ſome circumſtances, or whenever the ſame may be convenient or deſirable, I employ the fluid-metals, or mixtures of metals, in the part of the caſe or veſſel expoſed to the greateſt action of the fire, and in the parts leſs expoſed to the action of the fire I put oil, or other ſubſtances capable of bearing the requiſite heat without being converted into vapour.

"By this arrangement, and method of applying the ſurrounding heat, I not only obviate the neceſſity of employing ſteam of a great expanſive force round the ſteam veſſel or veſſels, or the working cylinder or cylinders, as already mentioned, to maintain them at the temperature required, but I am enabled to obtain from ſteam of a comparatively low temperature, or even from water itſelf, admitted into the ſteam veſſel or veſſels, all the effects that can be obtained from ſteam of a high temperature, without any of the riſk with which the production of the latter is accompanied, not only to the boiler and other parts of the machinery, but even to the lives of the workmen; for ſuch low ſteam, or even water (but in every caſe ſteam is preferable), being admitted into a ſteam veſſel or veſſels, or working cylinder or cylinders, kept at the requiſite higher temperature by the forementioned means, will there be expanded in any ratio required, and produce an effect in the working of the engine, which cannot otherwiſe be obtained but at a greater expence of fuel, or with the riſk of an exploſion. By this means I can make uſe of ſteam expanded in any required ratio, or of any given temperature, without the neceſſity of ever having the ſteam of any greater elaſticity than equal to the preſſure of the common atmoſphere.

"Another improvement which I make uſe of in ſteam-engines conſiſts in a method of preventing, as much as poſſible, the paſſage of any of the ſteam from that ſide of the piſton which is acted upon by the ſaid ſteam to the other ſide which is open to the condenſer; and this I effect in thoſe ſteam-engines known by the name of double-engines, by employing upon or above the piſton mercury or fluid metal or metals in an altitude equal to the preſſure of the ſteam. The efficacy of this arrangement will appear obvious, from attending to what muſt take place in working ſuch a piſton. When the piſton is aſcending, that is, when the ſteam is admitted below the piſton, the ſpace on its other ſide being open to the condenſer, the ſteam endeavouring to paſs up by the ſide of the piſton is met and effectually prevented by the column of metal equal or ſuperior to it in preſſure, and during the down-ſtroke no ſteam can poſſibly paſs without firſt forcing all the metal through. In working what is called a ſingle engine, a leſs conſiderable altitude of metal is required, becauſe the ſteam always acts on the upper ſide of the piſton. For ſingle-engines, oil or wax, or fat of animals, or ſimilar ſubſtances, in ſufficient quantity, will anſwer the purpoſe, if another improvement, which conſtitutes part of my ſaid invention, be applied to the engine, namely, to take care that in either the double or ſingle engine ſo to be worked, the outlet that conveys the ſteam to the condenſer ſhall be ſo poſited, and of ſuch a ſize, that the ſteam may paſs without forcing before it or carrying with it any of the metal or other ſubſtance employed that may have paſſed by the piſton; taking care at the ſame time to provide another exit for the metal or other ſubſtance collected at the bottom of the ſteam-veſſel or working-cylinder to convey the ſame into a reſervoir kept at a proper heat, whence it is to be conveyed to the upper ſide of the piſton by a ſmall pump worked by the engine or by any other contrivance. In order that the fluid metal or metals uſed with the piſton may not be oxidated, I always keep ſome oil or other fluid ſubſtance on its ſurface to prevent its coming in contact with the atmoſphere; and to prevent the neceſſity of employing a large quantity of fluid metal, I generally make my piſton of the depth of the column required, but of a diameter a little leſs than the ſteam-veſſel or working-cylinder, excepting where the packing or other fitting is neceſſary to be applied; ſo that, in fact, the column of fluid metal forms only a thin body round the piſton. In ſome caſes I make a hollow metallic piſton, and apply an altitude of fluid metal in the inſide of the ſame to preſs its outſide into contact with the ſteam-veſſel or working-cylinder.

"It may be neceſſary, however, to ſtate, that in applying my improved method of keeping the ſteam-veſſels of ſteam-engines at any required temperature to the engine known by the name of Savary's in any of its improved forms, in which a ſeparate condenſer has been introduced, I ſometimes employ oil, or any other ſubſtance lighter than water, and capable of being kept fluid in the temperature employed, without being converted into vapour, in the upper part of the tube or pipe attached to the ſteam-veſſel; by which means ſteam of any temperature may be uſed without being expoſed to the riſk of partial condenſation by the admiſſion of any colder body into the ſteam-veſſel; for the oil, or other ſubſtance employed for this purpoſe, ſoon acquires the requiſite temperature; and to prevent unneceſſary eſcape of heat, I conſtruct of, or line with, an imperfect conductor of heat, that part of the tube or pipe attached to the ſteam-veſſel which may not be heated exteriorly. And further (as is already the practice in ſome engines, and therefore not excluſively claimed by me), I cauſe the water raiſed by the engine to paſs off through another aſcending tube than the one attached to the ſteam-veſſel, but connected with it at ſome part lower than the oil or other ſubſtance employed in it is ever ſuffered to deſcend to the working of the engine. The improvement which I have juſt mentioned, of introducing oil into the pipe attached to the ſteam-veſſel of ſuch engines, may alſo be introduced without applying heat externally to the ſteam-veſſel; but in this caſe, part of the effect which would otherwiſe be gained is loſt."

From the foregoing details, there ſeems to be a reaſonable ground to hope that a great deſideratum, *a real ſaving of fuel*, will be effected by Mr. Woolf's improvements, founded on his diſcovery of the ratio in which ſteam of any high temperature can expand itſelf. It is certainly a new and curious fact, that ſteam may, by mere additions of temperature, be increaſed in volume in the way he ſtates, and ſtill be equal in force to the common atmoſphere. The advantage which he gains, or, in other words, the ſaving which he effects in the quantity of fuel, depends entirely on the correctneſs of this fact; for, according to the ideas hitherto entertained, ſteam of the ſtrength of about thirty pounds the inch, above the common atmoſphere, ought only to effect the work of two atmoſpheres more than ſteam of 212°; but according to Mr. Woolf, by proper management, it may be made to produce the work of thirty atmoſpheres!

By what we have juſt ſtated, we would not be underſtood to call in queſtion the accuracy of Mr. Woolf's experiments; for he has had ſo much practical experience in his capacity of engineer to one of the largeſt concerns in London (Meſſrs. Meux's brewhouſe), that it would be difficult to believe he could be miſtaken on a point of ſo much importance. His invention will ſoon be put to the teſt of experience; a large engine being now erecting under his direction at Meſſrs. Meux's, beſides others in different manufactories. Should they anſwer the expectations that have been formed of them, Mr. Woolf's diſcovery will form a new and ſingular epoch in the hiſtory of an engine, which had previouſly been brought to a ſtate of ſuch high perfection as almoſt to exclude the hope of any further improvement.

Mr. Woolf has alſo invented ſome boilers for ſteam-engines, different from the uſual conſtruction; in which, beſides employing ſafety-valves, he has introduced a valve of a new conſtruction to regulate the quantity and power of the ſteam paſſing from the boiler. In theſe the ſteam-box is joined to the neck or outlet for the ſteam by flanges. The top or cover of the ſteam-box, which is well ſecured in its place, has a hole through it for the rod of the valve, ſo contrived as to anſwer the purpoſe of a ſtuffing-box to make the rod work up and down ſteam-tight, the ſtuffing being kept in its place by the uſual means, well known to engineers. By means of a pin or nail, and two vertical pieces, the piſton-rod is made faſt to a cover joined to the hollow cylinder. The cover fits ſteam-tight into a collar, which is made faſt on the flange before mentioned. The cylinder is open at the bottom, having a free communication with the main cylinder, and has three vertical ſlits. The ſum of the ſurface of all theſe ſlits or openings is equal to the area of the opening of the collar in which the cylinder works. When the ſteam acquires a ſufficient degree of elaſtic force to raiſe the valve (that is, the hollow cylinder with its cover and rod), and whatever weight it may be loaded with, then the openings, getting above the ſteam-tight collar, allow the ſteam to paſs into the ſteam-box. The quantity of ſteam that paſſes is proportioned to the elaſtic force it has acquired, and the weight with which the valve is loaded; and the riſe of the openings above the collar will be in the ſame proportion. This valve may be loaded in any of the uſual methods; but Mr. Woolf prefers one in which the upper part of the rod is joined by means of a chain to a quadrant of a circle with an arm projecting from it, which carries a weight that may be moved near to or further from the centre of the quadrant, according as the preſſure of the valve is wiſhed to be increaſed or diminiſhed. As the valve riſes, the weight moves upward, giving an increaſed reſiſtance to the further riſing of the valve, proportioned to the greater horizontal diſtance from the centre of the quadrant, which the weight attains by its riſe in the ſaid arch, that diſtance being meaſured in the horizontal line by a perpendicular from the ſaid line paſſing through the centre of the weight. Thus the rod joining the quadrant and the great weight, may be made to ſerve at the ſame time as an index to the perſon who attends the fire, nothing more being neceſſary for this purpoſe than to graduate the arch deſcribed by the end of the rod. In the ſide of the ſteam-box there is an opening to allow the ſteam to paſs from it by a pipe or tube to the ſteam-engine, or to any ſecondary boiler, or for the purpoſe of conveying and applying it to any other veſſel or uſe to which ſteam is applicable. A figure of this ſteam-valve may be ſeen in Tilloch's Philoſophical Magazine, No. 66.

As to Mr. W.'s propoſed improvements in boilers, they conſiſt, firſt, of two or more cylindrical veſſels properly connected together, and ſo diſpoſed as to conſtitute a ſtrong and fit receptacle for water, or any other fluid intended to be converted into ſteam, whether at the uſual heats or at temperatures and under preſſures uncommonly high; and alſo to preſent an extenſive portion of convex ſurface to the current of flame, or heated air or vapour from a fire: ſecondly, of other cylindrical receptacles placed above theſe cylinders, and properly connected with them, for the purpoſe of containing water and ſteam, and for the reception, tranſmiſſion, and uſeful application of the ſteam generated from the heated water or other fluid: and, thirdly, of a furnace ſo adapted to the cylindrical parts juſt mentioned, as to cauſe the greater part of the ſurface of all and each of them, or as much of the ſaid ſurface as may be convenient or deſirable, to receive the direct action of the fire, or heated air and vapour.

The principal of theſe improvements, if they be really ſuch, occurred to Mr. Blakey long ago, as was obſerved by Mr. Hornblower. Blakey's boiler and furnace are repreſented in fig. 9. pl. XXIII. Mr. Woolf's may be ſeen in No. 65 of the Philoſophical Magazine.

From the whole of the preceding accounts the reader will, we hope, be able to obtain more correct and uſeful information relative to the nature and manner of operation of the principal ſteam-engines than can be obtained from any Treatiſe of Mechanics yet publiſhed in this country. Yet, as the ſubject is of great importance, and furniſhes variety ſufficient to fill a volume of itſelf, we beg to refer thoſe who wiſh to learn the conſtruction of other kinds of theſe uſeful machines, to the different volumes of *Nicholſon's Journal*, *Tilloch's Magazine*, the *Repertory of Arts and Manufactures*, and the *Architecture Hydraulique of Prony*.

We ſhall conclude with a hint reſpecting the economical ſupply of ſteam-engines. In many manufactories and public works the ſteam may be generated by the waste heat ariſing from ſome eſſential branch of the concern; and thus great part of the daily expence of the machine may be ſaved. Mr. Blakey, who paid conſiderable attention to this point, ſays, in his Miſcellaneous Works, "The moſt complete engine I made was in 1783 at Namur, for a rolling mill; it raiſed 7500 pounds of water every condenſation, which fell on wheels of 15 and 16 feet diameter; *the waſte heat for heating the metal was ſufficient to make more ſteam than was wanted to work the engine.*" Again, "I have brought my engines to work ſugar-mills with no other power than that of the *waſte heat* coming from the fire for boiling ſugar; by which means *all the charge of cattle and of water-mills for ſugar works will be ſaved.*" And, once more, there is "a capital amendment made by General Conway, and which defrays *the whole expence of fuel.* This is done by means of the flame or heat that comes from coaking ovens, which heat creates all the ſteam neceſſary to work the engine. *By theſe means all iron foundries heated with coke can work their engines clear of all expence of fire.*"

STEEL-YARD, an inſtrument uſed for weighing of goods, &c.; the theory of which was conciſely ſtated in art. 138 of our firſt volume, and ſucceeded by a few remarks on its conveniences and inconveniences. In addition to what was there obſerved we may now ſtate, that ſteel-yards, in the common purpoſes of commerce, have two advantages over balances. 1. That their axis of ſuſpenſion is not loaded with any other weight than that of the merchandiſe, the conſtant weight of the apparatus itſelf excepted; while the axis of the balance, beſides the weight of the inſtrument, ſuſtains a weight double to that of the merchandiſe. 2. The uſe of the balance requires a conſiderable aſſortment of weights, which cauſes a proportional increaſe in the price of the apparatus, independently of the chances of error which it multiplies, and of the time employed in producing an equilibrium. Theſe motives induced C. Paul, inſpector of weights at Geneva, to employ his thoughts on the means of ſo far improving ſteel-yards, that, either in delicate operations of the arts, or in thoſe of the ſame kind which are often ſo neceſſary in the practice of the phyſical ſciences, theſe inſtruments might be ſubſtituted with advantage for common balances. In order that we may better explain in what the improvements of theſe ſteel-yards conſiſt, it will be proper to point out what were the faults of the common ones.

1. There were none of them, in which the points of ſuſpenſion were exactly in the prolongation of the line of the diviſions of the beam; a circumſtance which neceſſarily changed

the relation between the arms of the lever, the power, and the reſiſtance, according as the direction of the beam was changed from a horizontal poſition. We have ſeen ſteel-yards, in which a degree only of difference in the inclination of the beam produced the difference of more than a pound in the reſult.

2. When the ſhell, the beam, and weight, are made at hazard, a perſon who poſſeſſes a ſteel-yard cannot know when the inſtrument is deranged; and even an artiſt cannot repair it, but by repeated trials, and with a great loſs of time.

3. The conſtruction of the common ſteel-yards, which have a ſmall and a large ſide, renders it neceſſary to invert them frequently; a laborious operation when theſe inſtruments are heavy, and which expoſes the axes to the danger of damage by the effect of the ſhocks which that turning occaſions.

As theſe double ſides renders it neceſſary to have a beam very ſtraight, in order that it may be leſs faulty, it readily bends, which is a new ſource of error; and, the face which bears the numbers being narrow in proportion, it is difficult to form on it numbers ſufficiently viſible. Theſe inconveniences are all avoided by the conſtruction of C. Paul, which preſents, beſides, ſeveral other advantages not poſſeſſed by the old ſteel-yards.

1. The centres of the movement of ſuſpenſion, or the two conſtant centres, are placed on the exact line of the diviſions of the beam; an elevation almoſt imperceptible in the axis of the beam, deſtined to compenſate for the very ſlight flexion of the bar, alone excepted.

2. The apparatus, by the conſtruction of the beam, is balanced below its centre of motion; ſo that when no weight is ſuſpended, the beam naturally remains horizontal, and reſumes that poſition when removed from it, as alſo when the ſteel-yard is loaded and the weight is at the diviſion, which ought to ſhew how much the merchandiſe weighs. The horizontal ſituation in this ſteel-yard, as well as in the others, is known by means of the tongue, which riſes vertically above the axis of ſuſpenſion.

3. It may be diſcovered that the ſteel-yard is deranged, if, when not loaded, the beam does not remain horizontal.

4. The advantage of a great and a ſmall ſide (which in the others augments the extent of their power of weighing) is ſupplied by a very ſimple proceſs, which accompliſhes the ſame end with ſome additional advantages. This proceſs is to employ, on the ſame diviſion, different weights. The numbers of the diviſions on the bar, point out the degree of heavineſs expreſſed by the correſponding weights. For example, when the large weight of the large ſteel-yard weighs eighteen pounds, each diviſion it paſſes over on the bar is equivalent to a pound;

the ſmall weight, weighing eighteen times leſs than the large one, will repreſent, on each of theſe diviſions, the eighteenth part of a pound or ounce; and the oppoſite face of the bar is marked by pounds at each eighteenth diviſion. In this conſtruction, therefore, we have the advantage of being able, by employing both weights at once, to aſcertain, for example, almoſt within an ounce, the weight of 500 pounds of merchandiſe. It will be ſufficient to add what is indicated by the ſmall weight in ounces, to that of the large one in pounds, after an equilibrium has been obtained by the poſition of the two weights, viz. the large one placed at the next pound below its real weight, and the ſmall one at the diviſion which determines the number of ounces to be added.

5. As the beam is graduated only on one ſide, it may have the form of a thin bar, which renders it much leſs ſuſceptible of being bent by the action of the weight, and affords room for making the figures more viſible on both the faces.

6. In theſe ſteel-yards the diſpoſition of the axes is not only ſuch that the beam repreſents a mathematical lever without weight; but in the principle of its diviſion, the interval between every two diviſions is a determined and aliquot part of the diſtance between the two fixed points of ſuſpenſion; and each of the two weights employed has for its abſolute weight the unity of the weight it repreſents, multiplied by the number of the diviſions contained in the interval between the two conſtant centres of motion. Thus, ſuppoſing the arms of the ſteel-yard divided in ſuch a manner that ten diviſions are exactly contained in the diſtance between the two conſtant centres of motion, a weight to expreſs the pounds on each diviſion of the beam muſt really weigh ten pounds; that to point out the ounces on the ſame diviſions, muſt weigh ten ounces, &c. So that the ſame ſteel-yard may be adapted to any ſyſtem of meaſures whatever, and in particular to the decimal ſyſtem, by varying the abſolute heavineſs of the weights, and their relation with each other. The application of this principle will be ſeen hereafter in the deſcription of the ſteel-yard, to which C. Paul, with great propriety, has given the name of *univerſal ſteel-yard.*

But to trace out, in a few words, the advantages of the ſteel-yards conſtructed by C. Paul for commercial purpoſes, we ſhall only obſerve, 1. That the buyer and ſeller are certain of the correctneſs of the inſtrument, if the beam remains horizontal when it is unloaded and in its uſual poſition. 2. That theſe ſteel-yards have one ſuſpenſion leſs than the old ones, and are ſo much more ſimple. 3. That by theſe means we obtain, with the greateſt facility, by employing two weights, the exact weight of merchandiſe, with all the approximation that can be deſired, and even with a greater preciſion than that given by common balances. There are few of theſe which, when loaded with 500 pounds at each end, give decided indications of an ounce variation; and the ſteel-yards of C. Paul poſſeſs that advantage, and coſt one-half leſs than balances of equal dominion. 4. In the laſt place we may verify, every moment, the juſtneſs of the weights, by the tranſpoſition which their ratio to each other will permit; for example, by obſerving whether, when the weight of one pound is brought back one diviſion, and the weight of one ounce carried forwards eighteen diviſions, the equilibrium ſtill remains.

If, inſtead of aſcertaining the weight of the merchandiſe in pounds, you wiſhed to find it according to the new ſyſtem in decagrammes, hectogrammes, and kilogrammes, it will be ſufficient to ſubſtitute, for the ordinary weights, an aſſortment of three weights bearing the above names. Theſe three weights are the decuple one of the other; and the abſolute weight of that called kilogramme, is to the abſolute weight of that called pound, in the exact ratio of theſe two quantities. It may be here ſeen, that, by adapting to the ſteel-yard a ſyſtem of three weights, we may arrive at the ſecond decimal, or the centiemes of the unity of the weights employed, and even without adding or changing any thing in the diviſion of the beam.

It is on this ſimple and advantageous principle that C. Paul has conſtructed his univerſal ſteel-yard. It ſerves for weighing in the uſual manner, and according to any ſyſtem of weights, all ponderable bodies to the preciſion of half a grain in the weight of a hundred ounces; that is to ſay, of a ten-thouſandth part. It is employed, beſides, for aſcertaining the ſpecific gravity of ſolids, of liquids, and even of the air itſelf, by proceſſes extremely ſimple, and which do not require many ſub-diviſions in the weights.

The beam of this ſteel-yard when unloaded reſts in equilibrio in a horizontal poſition. The ſhears are ſuſpended by a ſcrew to a croſs horizontal bar of wood ſupported by two vertical pillars, which reſt on the two extremities of a ſmall wooden box furniſhed with three drawers, and which ſerves as the ſtand of the apparatus. This beam is divided into 200 equal parts, beginning at its centre of motion. The diviſion is differently marked on the two faces: on the anterior face the numbers follow each other from 10 to 200, proceeding towards the extremity; and on the other face, the numbers are marked in the oppoſite direction. We ſhall ſoon explain the uſe of this difference in the order of numeration.

A ſmall vertical frame hangs from the croſs-bar nearly at the further extremity of the ſteel-yard, and is deſtined to prevent the oſcillation of the beam; it is placed at the proper height by means of the nut and ſcrew by which it is ſuſpended. Above the beam is a ſmall croſs-bar of braſs, ſuſpended by its two extremities from the croſs-bar of wood. Different weights are hooked to it, each having marked on it its particular value. And, in the laſt place, a ſmall mercurial thermometer having the two moſt uſual diviſions, viz. Fahrenheit's and Reaumur's, and deſtined to point out the temperature of the air and the water during the experiments. The axis of ſuſpenſion of the ſteel-yard reſts upon two beds of very hard well-poliſhed ſteel. The caſe is the ſame, but in a reverſed ſituation, with the axis which ſupports the hook, that ſerves for ſuſpending different parts of the apparatus, according to the purpoſe to which it is to be applied.

When you wiſh to employ it as a common ſteel-yard, you ſuſpend from it a braſs ſhell, which is an exact counterbalance for the weight of the beam when unloaded. The latter then aſſumes of itſelf a horizontal ſituation. You then ſearch for the equilibrium of the ſubſtance put into this ſhell, by placing at the proper place, on the beam, the weight and its fractions correſponding with the ſyſtem of weights adopted; and when you have found the equilibrium, you obſerve the weight indicated by the diviſions on which each of the weights employed is found, exactly in the ſame manner as is done in regard to the common ſteel-yard.

There is alſo, as part of the apparatus, a glaſs ſhell ſuſpended occaſionally in a jar filled to a certain height with water. This ſhell is intended for experiments relative to the ſpecific gravity of ſolids. It is in equilibrium, if, when immerſed into water at 20° of Reaumur, as far as the junction of the three ſilver wires by which it is ſupported, it exactly balances the weight of the beam unloaded.

When you wiſh then to try the ſpecific gravity of a ſolid, you firſt weigh it in air; but by putting it into the braſs ſhell, and then ſubſtituting the glaſs one, you weigh it in water. It is well known that the difference of theſe weights, employed as a diviſor of the total weight in air, gives for quotient the ſpecific gravity. Care muſt be taken, as in all experiments of the kind, that no bubble of air adheres to that part of the apparatus immerſed in the water, or to the ſubſtance, the weight of which is required, and which is immerſed alſo.

There is likewiſe a ſolid glaſs ball deſtined for the purpoſe of aſcertaining the ſpecific gravity of liquids, in the following manner:—This piece is furniſhed with a hook of fine gold, that it may be immerſed without inconvenience in acids. When it is ſuſpended to the hook of the ſteel-yard, and in the air, it is in equilibrium with the beam loaded at its extremity (either at the diviſion marked O (nothing) on the back ſide of the beam) with weights entitled *ſpecific*, and $\frac{1}{100}$ of ſpecific hooked on at the other.

This ball, immerſed in diſtilled water at 12° of Reaumur as far as the end of the ſtraight metal wire which ſuſpends it, is ſtill in equilibrium with theſe two weights placed in the following manner, viz. the large one at the diviſion in the middle of the beam marked *water* on the backſide of the beam, and the ſmall one at the diviſion O, that is to ſay, the extremity. When the apparatus is thus prepared, you fill a jar with the liquid, the ſpecific gravity of which you wiſh to aſcertain; ſuſpend the glaſs ball to the hook of the ſteel-yard, and immerſe it into the liquid till it riſes exactly above the ring from which the ball hangs, obſerving the temperature, and diſengaging carefully all the air-bubbles that may adhere to the ball; then remove the ſmall weight to the diviſion O at the end of the beam, and convey the large one as far as that diviſion, preceding that where the weight of the ball would raiſe the beam; and afterwards move the ſmall weight as far as the diviſion where the equilibrium will be reſtored, the beam being horizontal. Mark the diviſion at which the large weight is found, and add two cyphers; to this number add the indication immediately reſulting from the poſition of the ſmall weight, and the ſum of theſe two numbers gives the ſpecific gravity of the liquid, or its ratio with the weight of diſtilled water, to a ten-thouſandth part.

The larger balloon is uſed in trying the weight of any given kind of gas compared with that of atmoſpheric air, in the following manner:—The weight entitled *air-tare* is arranged in ſuch a manner that when placed in a notch, at the further extremity of the beam beyond the diviſions, it forms an equilibrium with the balloon exhauſted by the air-pump and ſuſpended from the hook of the ſteel-yard. If the ſteel-yard is not then in equilibrium, it is an indication that the inſtrument is deranged, or that the vacuum is not perfect. The air, the relative weight of which in regard to atmoſpheric air you wiſh to aſcertain, is to be introduced into the balloon, and the weight marked *air* is to be moved along the beam. The diviſion at which it ſtands when an equilibrium is produced will indicate, in hundredth parts of the weight of the volume of atmoſpheric air that could be contained in the balloon, the weight of the gas actually incloſed in it. This indication is read about the middle of the anterior part of the beam, where the words *atmoſpheric air* are marked.

Not ſatisfied with having procured to philoſophers, and thoſe fond of accurate experiments, an inſtrument extremely convenient for the cloſet, and of very extenſive uſe, C. Paul has endeavoured to render this apparatus portable, and has conſtructed various pocket ſteel-yards, with which the niceſt experiments may be made, and the quality of gold coin be aſcertained by the trial of its ſpecific gravity. They are conſtructed exactly on the ſame principles as the Roman ſmall ſteel-yard, but are neceſſarily leſs extenſive in their uſe. They cannot be employed, for example, in determining the ſpecific gravity of an aëriform fluid, and do not extend beyond 100 deniers of weight; but as they poſſeſs all the advantages of a balance, beſides thoſe peculiar to themſelves, they are extremely convenient for philoſophers who are obliged to travel.

A figure of this ſteel-yard and apparatus may be ſeen in Tilloch's Philoſ. Magazine, vol. iii.

Steelyards *to aſcertain animal ſtrength*, may readily be attached to almoſt any kind of machinery in which animals are the firſt movers: and it is much to be wiſhed that experiments were frequently made with them, in order that our knowledge on this point might be increaſed.

The following contrivance falling under this head, has been lately propoſed for determining the power of horſes drawing in mills. Let AB (fig. 10. pl. XXXII.) be the vertical ſhaft to which the horizontal horſe-poles AC, AD, are attached. Let one horſe work the machine by drawing at the ear E; but inſtead of the tranſverſe ſplinter-bar, to which the harneſs is fixed, being ſimply hung upon the hook *h*, let a good ſpring ſteel-yard be interpoſed between that croſs-bar and the hook, the graduations of which ſhall, when the machinery is put into motion, indicate the reſiſtance (in lbs.) overcome by the animal, including the weight of the maſs moved, the friction, &c. Near the extremity of the oppoſite horſe-pole AD, let there be fixed a ſtrong and correct common ſteel-yard, whoſe diviſions ſhall ſhew the various weights from 40 or 50 to 200 lbs. and whoſe centre of motion ſhall be at the point *f* on the fixed ſtand. Let the cord *c*, which is faſtened to the ſhorter arm of this ſteel-yard, paſs (with as little friction as poſſible) over the pulley *p*, and thus, being turned into the horizontal direction, or rather inclining a little upwards, let it be fixed to the croſs-bar of the harneſs of a ſecond horſe, equal in point of ſtrength to the former. Then, if the two horſes thus attached to the ears E and F be made to paſs over the walk in the ſame direction, following each other conſtantly at the diſtance of a ſemi-circumference; while that which draws at the ear E overcomes the whole preſſure and reſiſtance oppoſed by the work, the other which draws at F by the cord over the pulley *p*, will raiſe the weight *w* of the ſteel-yard; which, therefore, by being moved to and fro upon the arm *fi*, may be brought to exhibit an exact counterpoiſe, or meaſure of the exertion and power of the horſe. And in order to enſure the greateſt degree of accuracy in this reſpect, the motion of the two animals and the poſition of the weight *w*, ſhould be ſo adjuſted, that the ſame weight ſhould be ſhewn by the graduations both of the ſpring and of the lever ſteel-yard. The ſhaking of the machinery will in ſome meaſure diſturb the effect: but an ingenious manager of the experiments will find means of checking this: and as to the centrifugal force to which the weight *w* is expoſed, it will never be of material conſequence in any of the ſlow motions which will be produced by this kind of work.

Each experiment ſhould occupy the place of a fair day's work for the horſes; for the concluſions deduced from ſhorter and irregular efforts are always erroneous in exceſs, and ſhould be guarded againſt. The rate at which the animals move may readily be aſcertained from the known circumference of the walk, and the number of rounds they are obſerved to make in ten or fifteen minutes.

A ſlight modification will adapt this contrivance to the determination of the power of men puſhing at the bars of a capſtan: to this end it will only be neceſſary to have a ſufficiently ſtrong frame in form of a T, one end of which may be faſtened to a nooſe in the cord paſſing round the pulley *p*, while a man puſhes at the tranſverſe bar of the frame, with the ſame energy as he would employ at the capſtan bar.

By means of ſuch ſteel-yards properly applied to waggons, &c. upon tolerably ſmooth roads, and two horſes marching abreaſt (one drawing the load, the other raiſing the weight), experiments might be inſtituted to aſcertain the magnitude of the efforts of horſes when drawing in rectilinear paths.

In Deſaguliers's Experimental Philoſophy, vol. I. ſome ſteel-yards are deſcribed, by which the ſtrength of men may be aſcertained when ſtanding ſtill, and pulling or puſhing upwards or downwards: we had, at firſt, propoſed to deſcribe them in this place; but as all theſe contrivances are nearly on the ſame principle, and may eaſily be adapted to any particular purpoſe, we omit the minute deſcriptions and drawings to make room for other ſubjects.

STREAM-MEASURERS, are inſtruments by which the velocity of currents of water in rivers, mill-ponds, &c. may be determined.

In the introductory part of this volume, we ſpoke of the common and groſs methods of aſcertaining the velocity of running water in canals, &c. But as more ſcientific and accurate methods have been deviſed, it ſeems proper to inſert the beſt of them with which we are acquainted, in this place.

1. M. *Pitot* invented a ſtream meaſurer of a ſimple conſtruction, by means of which the velocity of any part of a ſtream may readily be found. This inſtrument is compoſed of two long tubes of glaſs open at both ends; one of theſe tubes is cylindrical throughout; the other has one of its extremities bent into nearly a right angle, and gradually enlarges like a funnel, or the mouth of a trumpet: theſe tubes are both fixed in grooves in a triangular priſm of wood; ſo that their lower extremities are both on the ſame level, ſtanding thus one by the ſide of the other, and tolerably well preſerved from accidents. The frame in which theſe tubes ſtand is graduated, cloſe by the ſide of them, into diviſions of inches and lines.

To uſe this inſtrument, plunge it perpendicularly into the water, in ſuch manner that the opening of the funnel at the bottom of one of the tubes ſhall be completely oppoſed to the direction of the current, and the water paſs freely through the funnel up into the tube. Then obſerve to what height the water riſes in each tube, and note the difference of altitudes; for this difference will be the height due to the velocity of the ſtream. It is manifeſt, that the water in the cylindrical tube will be raiſed to the ſame height as the ſurface of the ſtream, by the hydroſtatic preſſure: while the water entering from the current by the funnel into the other tube, will be compelled to riſe above that ſurface by a ſpace at which it will be ſuſtained by the impulſe of the moving fluid: that is, the momentum of the ſtream will be in equilibrio with the column of water ſuſtained in one tube above the ſurface of that in the other. In eſtimating the velocity by means of this inſtrument, we muſt have recourſe to the theory in art. 439. &c. vol. I. as corrected by the experiments in art. 460. Thus, if h, the height of the column ſuſtained by the ſtream, or the difference of heights in the two tubes, be in feet, we ſhall have $v = 6{\cdot}5\sqrt{h}$, nearly, the velocity, per ſecond, of the ſtream; if h be in inches, then $v = 22{\cdot}47 \sqrt{h}$, nearly.

It will be eaſy to put the funnel into the moſt rapid part of the ſtream, if it be moved about to different places until the difference of altitude in the two tubes becomes the greateſt. In ſome caſes it will happen, that the immerſion of the inſtrument will produce a little eddy in the water, and thus diſturb the accuracy of the obſervation; but keeping the inſtrument immerſed only a few ſeconds will correct this. The wind would alſo affect the accuracy of the experiments; it is, therefore, adviſable to make them when there is little or no wind. By means of this inſtrument a great number of curious and uſeful obſervations may eaſily be made: the velocity of water at various depths in a canal or river may be found with tolerable accuracy, and a mean of the whole drawn, or they may be applied to the correcting of the theory of waters running down gentle ſlopes. The obſervations may likewiſe be applied to aſcertain whether the augmentations of the velocities are in proportion to the increaſe of water paſſing along the ſame canal, or what other relation ſubſiſts between them, &c.

Where great accuracy is not required, the tube, with the funnel at bottom, will alone be ſufficient; as the ſurface of the water will be indicated with tolerable preciſion, by that part of the priſmatic frame for the tube which has been moiſtened by the immerſion.

M. Pitot likewiſe propoſed that a ſimilar inſtrument ſhould be uſed inſtead of a log to determine the rate at which a ſhip ſails. For this purpoſe, place in the middle of the veſſel, or as near as can be at the centre of its oſcillations two tubes of metal of three or four lines in diameter, one of them being ſtraight, the other bent at bottom, and enlarged into a conical funnel; the bottoms of both are to dip into the water of the ſea in which the veſſel ſails, and there will be no evil to apprehend from orifices ſo minute: into theſe metallic tubes are cloſely fitted two others of a convenient height for the obſervations. The water will riſe in the firſt of theſe tubes up to its level on the outſide of the ſhip; and in the ſecond up to a certain height, which will indicate, as above, the velocity of the veſſel: for the funnel being turned towards the prow of the ſhip, it will, in conſequence of the motion, be affected in like manner, as if it were plunged into the ſtream of a running water; and thus the velocity of the veſſel is found by the ſame theorem as that of the current. This method has lately been re-propoſed in this country, without any acknowledgments to M. Pitot. We do not, however, recommend its adoption aboard a ſhip; for, notwithſtanding its theoretical ingenuity, it is liable to many ſources of error in the practice, and would not, it is probable, furniſh more accurate meaſures of a ſhip's way than thoſe deduced from the log.

2. Another good and ſimple method of meaſuring the velocity of water in a canal, river, &c. is that deſcribed by the Abbé *Mann*, in his Treatiſe on Rivers, Philoſophical Tranſactions, vol. 69. It is this:—Take a cylindrical piece of dry light wood, and of a length ſomething leſs than the depth of the water in the river; about one end of it let there be ſuſpended as many ſmall weights as may keep the cylinder in a vertical or upright poſition, with its head juſt above water. To the centre of this

end fix a ſmall ſtraight rod, preciſely in the direction of the cylinder's axis: to the end that, when the inſtrument is ſuſpended in the water, the deviations of the rod from a perpendicularity to the ſurface of it, may indicate which end of the cylinder goes foremoſt, by which may be diſcovered the different velocities of the water at different depths; for when the rod inclines forward, according to the direction of the current, it is a proof that the ſurface of the water has the greateſt velocity; but when it reclines backward, it ſhews that the ſwifteſt current is at the bottom; and when it remains perpendicular, it is a ſign that the velocities at the top and bottom are equal.

This inſtrument, being placed in the current of a river or canal, receives all the percuſſions of the water throughout the whole depth, and will have an equal velocity with that of the whole current from the ſurface to the bottom at the place where it is put in, and by that means may be found, both with exactneſs and eaſe, the mean velocity of that part of the river for any determinate diſtance and time.

But to obtain the mean velocity of the whole ſection of the river, the inſtrument muſt be put ſucceſſively both in the middle and towards the ſides, becauſe the velocities at thoſe places are often very different from each other. Having by this means found the ſeveral velocities, from the ſpaces run over in certain times, the arithmetical mean proportional of all theſe trials, which is found by dividing the common ſum of them all by the number of the trials, will be the mean velocity of the river or canal. And if this medium velocity be multiplied by the area of the tranſverſe ſection of the waters at any place, the product will be the quantity running through that place in a ſecond of time.

If it be required to find the velocity of the current only at the ſurface, or at the middle, or at the bottom, a ſphere of wood loaded, or a common bottle corked with a little water in it, of ſuch a weight as will remain ſuſpended in equilibrium with the water at the ſurface or depth which we want to meaſure, will be better for the purpoſe than the cylinder, becauſe it is only affected by the water of that ſole part of the current where it remains ſuſpended.

Both the cylinder and the globe may be eaſily guided into that part which we want to meaſure by means of two threads or ſmall cords, which two perſons, one on each ſide of the canal or river, muſt hold and direct; taking care at the ſame time neither to retard nor accelerate the motion of the inſtrument.

SURFACE-PLANING *Machinery.* In October, 1802, a patent was taken out by Mr. Joſeph Bramah for machinery for the purpoſe of producing ſtraight, ſmooth, parallel ſurfaces, and curvilinear ſurfaces, on wood, and other materials requiring accuracy, in a manner much more expeditious and perfect than can be performed by the uſe of axes, ſaws, planes, and other cutting inſtruments, uſed *by hand.* As many particulars in the ſpecification of this patent are highly curious, and cannot fail to be very beneficial, we ſhall extract the greater part of it from the Repertory of Arts and Manufactures, vol. ii. N. S.

" The principal parts of my invention are as follows; that is to ſay, to ſhorten and reduce manual labour, and the conſequent expences which attend it, by producing the effects ſtated in my patent by the uſe of machinery, which may be worked by animal, elementary, or manual force; and which ſaid effects are to produce ſtraight, true, ſmooth, and parallel ſurfaces, in the preparation of all the component parts of work conſiſting of wood, ivory, horn, ſtone, metals, or any other ſort of materials, or compoſition uſually prepared, and render it *(them)* true and fit for uſe, by means of edge-tools of every deſcription. I do not reſt the merits of this my ſaid invention on any novelty in the general principle of the machinery I employ, becauſe the public benefit I propoſe will rather depend on new effects, produced by a new application of principles already known, and machinery already in uſe for other purpoſes, in various branches of Britiſh manufacture. This machinery, and the new manner of uſing it, with ſome improvements in the conſtruction, together with ſundry tools and appendages never in uſe before, are particularly deſcribed and explained hereunder.

" I mean to uſe and apply for the purpoſes above ſtated, every kind of edge-tool, or cutter, already known, either in their preſent ſhape, or with ſuch variations and improvements as the variety of operations I may encounter may ſeverally call for. But the tools, inſtead of being applied by hand, as uſual, I fix, as judgment may direct, on frames drove *(driven)* by machinery: ſome of which frames I move in a rotary direction round an upright ſhaft; and others having their ſhaft lying in a horizontal poſition, like a common lathe for turning wood, &c. In other inſtances I fix theſe tools, cutters, &c. on frames which ſlide in ſtationed grooves, or otherwiſe, and like the former calculated for connexion with, and to be driven by, machinery, all of which are hereafter further explained and particulariſed.

" The principal points on which the merits of the invention reſt are the following. Firſt, I cauſe the materials meant to be wrought true and perfect, as above deſcribed, to ſlide into contact with the tool, inſtead of the tool being carried by the hand over the work, in the uſual way.

"Secondly, I make the tool, of whatſoever cutting kind it be, to traverſe acroſs the work in a ſquare or oblique direction; except in ſome caſes, where it may be neceſſary to fix the tool or cutter in an immoveable ſtation, and cauſe the work to fall in contact with it by a motion, confining it ſo to do, ſimilar to the operations performed on a drawing-bench.

"Thirdly, in ſome caſes I uſe, inſtead of common ſaws, axes, planes, chiſels, and other ſuch inſtruments, uſually applied by hand; cutters, knives, ſhaves, planes, and the like, variouſly, as the nature of the work may render neceſſary; ſome in form of bent knives, ſpoke-ſhaves, or deep-cutting gouges, ſimilar to thoſe uſed by turners for cutting off the rougheſt part. I alſo apply planes of various ſhapes and conſtruction, as the work may require, to follow the former in ſucceſſion, under the ſame operation; and which latter I call furniſhers.

"Fourthly, theſe cutters, knives, &c. I fix on frames of wood, or metal, properly contrived for their reception, and from which they may be eaſily detached for the purpoſe of ſharpening, and the like—theſe I call cutter-frames. Theſe cutter-frames I move in caſes like thoſe on which the ſaws are fixed in a ſawing-mill, and ſometimes to reciprocate in a horizontal direction, confined and ſtationed, by grooves or otherwiſe, as may be found beſt calculated to anſwer the ſeveral works intended. In other inſtances, and which I apprehend will generally have the preference, I fix cutter-frames on a rotary upright ſhaft, turning on a ſtep, and carrying the frame round in a direction ſimilar to the upper mill-ſtone; and ſometimes I cauſe the frames to turn on a horizontal ſhaft, juſt reſembling the mandrel of a common turning-lathe, or thoſe machines uſed for cutting logwood, &c. for the dyers' uſes. When theſe frames are mounted in any of the foregoing directions for cutting, planes, &c. are fixed ſo as to fall ſucceſſionally *(ſucceſſively)* in contact with the wood or other materials to be cut, ſo that the cutter or tool calculated to take the rough and hilly part operates the firſt, and thoſe that follow muſt be ſo regulated as to reduce the material down to the line intended for the ſurface. Theſe cutter-frames muſt alſo have the property of being regulated by a ſcrew or otherwiſe, ſo as to approach nearer the work, or recede at pleaſure, in order that a deeper or ſhallower cut may be taken at diſcretion, or that the machine may repeat its action without raiſing or depreſſing the materials on which they act. The manner of thus regulating the cutter-frames, when on an upright ſhaft, is particularly deſcribed below. Theſe cutter-frames may be made of any magnitude and dimenſions the work requires, only obſerving to make the diameter of thoſe on the rotary plane ſo as to exceed twice the width of the materials to be cut, as the ſaid materials muſt ſlide ſo as to paſs the ſhaft on which the cutter-frame revolves, when on the upright principle.

" Fifthly, when I uſe upright ſhafts, for the purpoſe of carrying the cutter-frame as above deſcribed, I do not mean that the lower end or point of ſuch ſhafts ſhall come in contact with, or reſt on, the bottom of the ſtep or box in which they ſtand; neither do I mean that ſuch ſaid ſhafts ſhall reſt or turn on any ſtationed unalterable point at reſt, but the pivot or lower point of the ſhaft ſhall actually reſt and turn on a fluid body, ſuch as oil, or any other fluid proper for that purpoſe, a conſiderable portion of which is always to be kept between the lower point of the ſhaft and the bottom of the ſtep in which it works. The ſaid ſhafts may be either raiſed or depreſſed at pleaſure to any required altitude, by means of a greater or leſs quantity of the ſaid fluid being confined as aforeſaid between the end of the ſhaft and the bottom of the ſtep. This device* I deem of great conſequence in the fabrication of all kinds of machinery, where maſſy and heavy loaded upright ſhafts are uſed; and I perform it in the following manner; that is to ſay: The lower part of the ſhaft muſt be turned perfectly ſmooth and cylindrical, to a height ſomething above the greateſt diſtance or length the ſhaft will ever be required to be raiſed or depreſſed when in uſe. This part of the ſhaft I immerſe or drop into a hollow cylinder, which fits its circumference near enough to allow freedom of motion, but ſufficiently fitted to prevent ſhake. This cylinder I call the ſtep-cylinder, and *(which)* muſt be of a length nearly equal to that of the cylindrical part of the ſhaft above mentioned, ſo that when the point of the ſhaft reſts on the bottom of the cylinder, the parallel or cylindrical part may be ſomething above the top or upper end of the ſtep-cylinder. In the upper end of this ſtep-cylinder I make a ſtuffing-box, by means of a double-cupped leather, or other materials, ſurrounding the cylindrical part of the ſhaft, in ſuch a way as will cauſe the junction, when the ſhaft is paſſed through it, to remain water-tight under any preſſure that may be felt from the efforts of the fluid retained as before mentioned, to make its eſcape upwards through this part, *(which)* I have called the ſtuffing-box, when the ſhaft, with all its load, is paſſed through it, and immerſed in the cylinder below. When this is done, the injecting-pipe of a ſmall forcing-pump, ſimilar to thoſe I uſe in my patent preſs, muſt form a junction with the ſtep-cylinder in ſome part below the ſtuffing-box; then the pump being worked, the oil, or other fluid injected by it, will, by preſſing in all directions, cauſe the ſhaft to be raiſed from its reſt, on the bottom of the cylinder, and to be ſlided up through the ſtuffing-box juſt the ſame as the piſton of my patent preſs; and by this means the ſhaft, with all its incumbrance, and whatever may be its weight, may be raiſed to any given point at pleaſure, and at the ſame time it will be left reſting on the fluid under it, whatever the quantity or thickneſs of ſuch fluid may be between its point and the bottom of the ſtep-cylinder. By this means the ſhaft, with all its incumbent load, as aforeſaid, ſhould it even amount to hundreds or thouſands of tons, can be eaſily raiſed and depreſſed to any required point at pleaſure, by the alternate injunction *(injection)* or diſcharge of the fluid uſed, exactly the ſame as performed by my patent preſs as aforeſaid; and at the ſame time all friction will be avoided, except that of the ſtuffing-box, which will be comparatively trifling to that which would reſult from the reſting of ſuch a ſhaft on the bottom of the ſtep, in the uſual way. Thus will be gained the properties above ſtated; and in addition thereto, I think it may be inferred, that, provided the ſtuffing-box is kept perfectly fluid tight, ſuch a ſhaft, thus buoyed up by and turning in a proper fluid, may continue working for years, or perhaps hundreds of years, without a freſh ſupply of oil, or whatever other fluid ſubſtance is found the moſt proper to apply.

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* See Count de Thiville's ſpecification, publiſhed in the fourteenth volume of the firſt ſeries of the Repertory, or the Engliſh Encyclopædia, art. WATER-WORKS, for the developement of a ſimilar invention.

"Sixthly, the material that is to be cut and made true muſt be firmly fixed on a platform, or frame, made to ſlide with perfect truth, either on wheels or in grooves, &c. ſimilar to thoſe frames in a ſaw-mill on which the timber is carried to the ſaws. Theſe frames muſt be moved in a ſteady progreſſive manner, as the cutter-frame turns round either by the ſame power which moves the latter, or otherwiſe, as may be found to anſwer beſt in practice. This motion alſo muſt be under the power of a regulator; ſo that the motion of the ſliding-frame may be properly adjuſted according to the nature of the work. The motion of the cutter-frames muſt alſo be under the control of a regulator; ſo that the velocity of the tool in paſſing over the work may be made quicker or ſlower, as ſuch work may reſpectively require, to cauſe the cutter to act properly, and to the beſt advantage.

"Seventhly, I regulate the motions of both theſe parts of the apparatus, as aforementioned, by means of a new invention, which I call a univerſal regulator of velocity, and which is compoſed as follows; viz. I take any number of cog-wheels, of different diameters, with teeth, that will exactly fit each other through the whole, ſuppoſe ten, or any other number, but for example ſay ten, the ſmalleſt of which ſhall not exceed one inch in diameter, and the largeſt ſuppoſe ten inches in diameter, and all the reſt to mount by regular gradations in their diameters from one to ten. I fix theſe ten wheels faſt and immoveable, on an axis perfectly true, ſo as to form a cone of wheels. I then take ten other wheels, exactly the ſame in all reſpects as the former, and fix them on another axis, alſo perfectly true, and the wheels in conical gradation alſo; but theſe latter wheels I do not fix faſt on their axis, like the former, but leave them all looſe ſo as to turn upon the ſaid axis, contrary to the former which are fixed. All theſe latter wheels I have the power of locking by a pin, or otherwiſe, ſo that I can at diſcretion lock or ſet faſt any ſingle wheel at pleaſure. I then place the two axises *(axes)* parallel to each other, with the wheels which form the two cones, as above deſcribed, in reverſe poſition, ſo that the large wheel at the one end of the cone may lock its teeth into the ſmalleſt one in the cone oppoſite, and likewiſe *vice verſa*. Then ſuppoſe the axis on which the wheels are permanently fixed to be turned about, all the wheels on the other axis will be carried round with an equal velocity with the former, but their axis will not move. Then lock the largeſt wheel on the looſe axis, and by turning about the faſt *(faſtened)* axis as before, it muſt make ten revolutions, while the oppoſite performs but one: then by unlocking the largeſt wheel and locking the ſmalleſt one at the contrary end of the cone in its ſtead, and turning as before, the faſt *(faſtened)* axis will then turn the oppoſite ten times while itſelf only revolves once. Thus the axes, or ſhafts, of theſe cones, or conical combination of wheels, may turn each other reciprocally, as one to ten, and as ten to one; which collectively produces a change in velocity under a uniform action of the *primum mobile*, as ten to a hundred: for when the ſmall wheel on the looſe axis is locked, and the faſt one makes ten revolutions, the former will make one hundred. And by adding to the number of thoſe wheels and extending the cones which may be done *ad infinitum*, velocity may be likewiſe infinitely varied by this ſimple contrivance—A may turn B with a ſpeed equal to thouſands or millions of times its own motion; and by changing a pin and locking a different wheel, as above deſcribed, B will turn A in the ſame proportion, and their power will *(be) transferred to each, in proportion as their velocities, reciprocally*. Here is then a univerſal regulator at once for both power and velocity. In ſome inſtances I produce a like effect by the ſame neceſſary number of wheels, made to correſpond in conical order, but inſtead of being all conſtantly mounted on the axises *(axes)* or ſhafts, as above deſcribed, they will reciprocally *(be)* changed from one axis to the other in ſingle pairs, match according to the ſpeed or power wanted, juſt as in the former inſtance. This method will have in all reſpects the ſame effect, but not ſo convenient as when the wheels are all fixed, &c.

"Eighthly, when ſpherical ſurfaces are to be produced perfectly true, and parallel to *(equidiſtant from)* their centres in all directions, I uſe a tool, or cutter, of a proper ſhape, according to the nature of the materials to be cut. This tool muſt be fixed on a cutter-frame, faſtened to the reſt of any common lathe, ſo as to preſent its point exactly to a line drawn through the centre of the mandrel of the lathe horizontally, and the ſaid frame on which the cutter is fixed muſt have the capacity of drawing out, at pleaſure, to any required diſtance, to accommodate the diameter of the ſphere to be cut or turned true. This cutter-frame muſt be likewiſe made to turn upon a centre or pin, very firm, and ſteadily fixed on the reſt above mentioned, ſo as to enable the cutter to be turned by its frame round a centre exactly perpendicular to the centre of the lathe or line, before mentioned, by which the altitude of the tool's point is to be regulated; when this is done, and the wood or other materials fixed on the lathe in the uſual way, the cutter-frame muſt be drawn nearer, or farther diſtant from the centre on which it turns, to accommodate the diameter, juſt the ſame as the common reſt. If the materials be rough, and require to be reduced to a ſpherical form by gradations, the work may be repeatedly gone over by the cutter, before it reaches the diameter propoſed. By this ſimple apparatus the difficulty of turning perfect ſpheres is overcome; as it muſt be obvious to any perſon of the moſt ordinary capacity in mechanics, that while the work is turning in the lathe in a vertical direction, and the tool or cutter is by the hand, or otherwiſe, turned, at the ſame time, in a perfectly horizontal direction, round a centre, oppoſite to the actual centre of the ſphere, the point of the tool or cutter muſt, of neceſſity, generate or turn a perfect ſphere, true in all directions, without the ſmalleſt attention or aſſiſtance from the uſe of the inſtrument. I mention here the application of the cutter-frame to a common lathe, conceiving it will, by ſuch an explanation, be more familiarly underſtood without a drawing; but, by this method, ſpheres of any practical magnitude may be cut with perfect eaſe and certainty.

"Ninthly, when concave ſurfaces are to be produced perfectly true, ſmooth, and parallel to *(equidiſtant from)* their reſpective ſpherical centres, the work is fixed on a machine the ſame in all reſpects as the common turning lathe, as in the inſtance laſt referred to: I then fix a tool or cutter on a centre, exactly in a line, both perpendicular to, and on a level with the exact centre of the ſhaft or mandrel on which the work revolves: and which cutter or tool projects to the required radial diſtance with its point, ſo that when the work goes round by the revolution of the lathe, the tool or cutter at the ſame time revolving round its centre, a ſpherical concave will be generated and produced by the fluction* of its point, as in the inſtance of the convex ſphere.

"Tenthly, I convert ſolid wood, or other materials, into a thin concave ſhell, ſimilar to a diſh, I cut them alternately out of each other, beginning at the ſmalleſt, by means of another tool or cutter, likewiſe moving on a ſtationed centre, as before, exactly on a level with, and perpendicularly true with the centre of the mandrel or ſhaft of the machine on which the work is fixed. This tool, or cutter, is made at its exterior point, or cutting end, of ſuch a ſhape as beſt ſuits the nature of the work; and its ſhank, or ſtem, is bent to the exact circle the concave is meant to be: it is then fixed on an arm or frame calculated to receive others of different circles, according to the work; in fact the ſame frame may be uſed which is above deſcribed to hold the tool for cutting ſpheres, either of the concave or convex kind. The tool muſt be fixed on this frame or arm, as above mentioned, at ſuch a radial diſtance from the centre on which the frame or arm turns, ſo as to form a quadrant with one leg, turning on its centre, and the tool forming the periphery with its cutting point projecting to the line of the deficient leg. Before this tool begins its action, a common reſt muſt be applied cloſe to the face of the work, in order to ſupport the tool when it begins its cut; and on which reſt the tool will ſlide till its point proceeds under the control of the centre on which its frame is fixed, until it reaches the horizontal line of the lathe's centre, when the part cut off, or the inner diſh, will fall from the ſtock, and leave the reſt for the operation of another tool, of a larger circle. Thus the operation may be repeated till the whole lump is converted according to the intentions of the owner.

SYPHON, with Mr. Cloſe's new application of it to convey water *above* the level of the reſervoir. See CRANE.

TEETH OF WHEELS, and LEAVES *of pinions*, require great care and judgment in their formation, that they may neither clog the machinery with unneceſſary friction, nor act ſo irregularly as to produce any inequalities in the motion, and a conſequent wearing away of one part before another is much affected by the work.

Several eminent mathematicians upon the continent, and a few in England and Scotland, have directed their inveſtigations towards a ſubject ſo eſſential to the perfection of machinery: yet, although Roemer, Varignon, De la Hire, Camus[*], Euler,[*] Kaeſtner, and Robiſon, have turned their thoughts to this object, and have ſtruck out ſome rules of ready application in practice, it is to be regretted that theſe rules have been little followed by practical mechanics, moſt of whom have in this caſe been more inclined to follow in their conſtructions the rules of Imiſon and others, though completely deſtitute of mechanic principle.

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* Compared with the record.

As the conſtruction of teeth of a proper form is exceedingly eaſy, we beg to recommend it earneſtly to practical men, and as we merely touched upon the ſubject in our firſt vol. (art. 147,) it may not be amiſs to enter a little into detail here, availing ourſelves, for the moſt part, of the judicious remarks juſt publiſhed by Mr. Brewſter.

It has been long known to mathematicians, and need not here be demonſtrated, that one wheel will not drive another with uniform velocity, unleſs the teeth of one or of both wheels have their faces formed into a curve, generated *after the manner of an epicycloid*, comprehending, under curves of this kind, thoſe which are formed by evolving the circumferences of circles. But in order to inſure a uniformity of preſſure and velocity in the action of one wheel upon another, it is not abſolutely neceſſary that the teeth either of one or both wheels be exactly epicycloids, in the ſenſe to which geometers commonly reſtrict that term. If the teeth of one of them be either circular or triangular, with plain ſides, or like a triangle with its ſides converging to the centre of the wheel, or, in ſhort, of any other form, this uniformity of force and motion will be attained, provided that the teeth of the other wheel have a figure which is compounded of that of an epicycloid, and the figure of the teeth of the firſt wheel. De la Hire has ſhewn, in a variety of caſes, how to find this compound curve: and we have lately examined a mill in which ſome teeth have been thus conſtructed with great ſkill and ſucceſs. But as it is often difficult to deſcribe this compound curve, and ſometimes impoſſible to diſcover its nature, we ſhall endeavour to ſelect ſuch a form for the teeth as may be eaſily deſcribed by the practical mechanic, while it enſures a uniformity of preſſure and velocity. In order to avoid circumlocution and obſcurity, we ſhall call, as is cuſtomary with practical men, the ſmall wheel (which is ſuppoſed always to be driven by a greater one) the *pinion*, and its teeth, the *leaves* of the pinion. The line which joins the centres of the wheel and pinion may be called the *line of centres*. Now there are three different ways in which the teeth of one wheel may act upon the teeth of another: and each of theſe modes of action requires a different form for the teeth.

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[*] Camus's popular diſſertation on this ſubject may be found in the ſecond vol. of his Courſe of Mathematics, the edition of 1767; the edition of 1781 does not contain it. Euler's paper is inſerted in *Nov. Comment. Petropol. tom.* 5. 1754, 1755. It will be intereſting to mathematicians, as it exhibits ſtrong traces of his maſterly hand: but it is too abſtruſe to be recommended to the practical mechanic.

I. When the teeth of the wheel begin to act upon the leaves of the pinion juſt as they arrive at the line of centres; and, when their mutual action is carried on after they have paſſed this line.

II. When the teeth of the wheel begin to act upon the leaves of the pinion, before they arrive at the line of centres, and conduct them either to this line, or a very little beyond it.

III. When the teeth of the wheel begin to act upon the leaves of the pinion, before they arrive at the line of the centres, and continue to act after they have paſſed this line.

I. The firſt of theſe modes of action is recommended by Camus and De la Hire, the latter of whom has inveſtigated the form of the teeth ſolely for this particular caſe. When this mode of action is adopted, the acting faces of the leaves of the pinion ſhould be parts of an *interior epicycloid* generated by a circle of any diameter rolling upon the concave ſuperficies of the pinion, and the acting faces of the teeth of the wheel ſhould be portions of an *exterior epicycloid* formed by the *ſame* generating circle rolling upon the convex ſuperficies of the wheel.

Now it is demonſtrable (ſee the article Cycloid, Supp. Engliſh Encyclo.) and has before been mentioned in our article Parallel *motions*, that when one circle rolls within another whoſe diameter is double that of the rolling circle, the line generated by any point of the latter will be a *ſtraight line*, tending to the centre of the larger circle. If the generating circle, therefore, mentioned above, ſhould be taken with its diameter equal to the radius of the pinion, and be made to roll upon the concave ſuperficies of the pinion, it will generate a ſtraight line tending to the pinion's centre, which will be the form of the acting faces of its leaves; and the teeth of the wheel will, in this caſe, be exterior epicycloids, formed by a generating circle, whoſe diameter is equal to the radius of the pinion, rolling upon the convex ſuperficies of the wheel. This form of the teeth, viz. when the acting faces of the pinion's leaves are right lines tending to its centre, is exhibited in fig. 14. pl. XXXII. and is perhaps the moſt advantageous, as it requires leſs trouble, and may be executed with greater accuracy than if the epicycloidal form had been employed: it is juſtly recommended both by De la Hire and Camus as particularly advantageous in clock and watch work.

The attentive reader will perceive that, in order to prevent the teeth of the wheel from acting upon the leaves of the pinion, before they reach the line of centres, and that one tooth of the wheel may not quit the leaf of the pinion till the ſucceeding tooth begins to act upon the ſucceeding leaf, there muſt be a certain proportion between the number of leaves in the pinion and the number of teeth in the wheel, or between the radius of the pinion and the radius of the wheel, when the diſtance of the leaves is given. But in machinery the number of leaves and teeth are always known from the velocity which is required at the working point of the machine: it becomes a matter, therefore, of great importance, to determine with accuracy the relative radii of the wheel and pinion.

For this purpoſe let A, fig. 14. be the pinion, having the acting faces of its leaves ſtraight lines tending to the centre, and B (not ſhewn in the figure) the centre of the wheel; AB will be the diſtance of their centres. Then, as the tooth C is ſuppoſed not to act upon the leaf A *m* till it arrives at the line AB, it ought not to quit A *m* till the following tooth F has reached the line AB. But ſince the tooth always acts in the direction of a line drawn perpendicular to the face of the leaf A *m* from the point of contact; the line CH, drawn at right angles to the face of the leaf A *m*, will determine the extremity of the tooth CD, or the laſt part of it, which ſhould act upon the leaf A *m*, and will alſo mark out CD for the depth of the tooth. Now, in order to find AH, HB, and CD, put a for the number of teeth in the wheel, b for the number of leaves in the pinion, c for the diſtance of the pivots A and B, and let x repreſent the radius of the wheel, and y that of the pinion. Then, ſince the circumference of the wheel is to the circumference of the pinion as the number of teeth in the one to the number of leaves in the other, and as the circumferences of circles are proportional to their radii, we ſhall have $a : b :: x : y$, or by compoſition $a+b : b :: c : y$ (c being equal to $x+y$), and conſequently the radius of the pinion, viz. $y = \frac{cb}{a+b}$; then, by inverting the firſt analogy, we have $b : a :: y : x$, and conſequently the radius of the wheel, viz. $x = \frac{ay}{b}$; y being now a known number.

Now, in the triangle AHC, right-angled at C, the ſide AH is known, and likewiſe all the angles (HAC being equal to $\frac{360}{b}$); the ſide AC, therefore, can be eaſily found by plane trigonometry. Then, in the oblique-angled triangle ACB, the angle CAB, equal to HAC, is known, as well as the two ſides AB, AC, which contain it; the third ſide, therefore, viz. CB, may be determined; from which DB, equal to HB, already found, being ſubtracted, there remains CD for the depth of the teeth. When the action is carried on after the line of centres, it often happens that the teeth will not work in the hollows of the leaves. In order to prevent this, the angle CBH muſt always be greater than half the angle HBP. The angle HBP is equal to 360 degrees, divided by the number of teeth in the wheel, and CBH is eaſily found.

Inſtead of pinions our mill-wrights frequently ſubſtitute lanterns or trundles, conſiſting of round ſtaves fixed by both ends nearly at the circumferences of two equal circular pieces of board; and theſe may often be adopted with great propriety, provided the teeth of the wheel have a proper form aſſigned to them. As the form recommended by ſeveral writers, and even by Belidor, is by no means accurate, we ſhall here call the reader's attention to the conſtruction pointed out by Mr Brewſter, which furniſhes a ready method of greatly diminiſhing the friction ariſing from the mutual action of the teeth.

Let A, pl. XXXII. fig. 13. be the centre of the pinion or ſmall wheel TCH, whoſe teeth are circular like ICR, having their centres in the circle PDE. Upon B, the centre of the large wheel, at the diſtances BC, BD, deſcribe the circles FCK, GDO; and with PDE, as a generating circle, form the exterior epicycloid DNM, by rolling it upon the convex ſuperficies of the circle GDO. The epicycloid DNM thus formed would have been the proper form for the teeth of the large wheel GDO, had the circular teeth of the ſmall wheel been infinitely ſmall; but as their diameter muſt be conſiderable, the teeth of the wheel ſhould have another form. In order to determine their proper figure, divide the epicycloid DNM into a number of equal parts, 1, 2, 3, 4, &c. as ſhewn in the figure, and let theſe diviſions be as ſmall as poſſible. Then, upon the points 1, 2, 3, &c. as centres, with the diſtance DC equal to the radius of the circular tooth, deſcribe portions of circles ſimilar to thoſe in the figure; and the curve OPT, which touches theſe circles, and is parallel to the epicycloid DNM, will be the proper form for the teeth of the large wheel.

In order that the teeth may not act upon each other till they reach the line of centres AB, the curve OP ſhould not touch the circular tooth ICR till the point O has arrived at D. The tooth OP, therefore, will commence its action upon the circular tooth at the point I, where it is cut by the circle DRE. On this account, the part ICR of the cylindrical pin being ſu-portions, may be cut off, and the teeth of the ſmall wheel will be ſegments of circles ſimilar to the ſhaded parts of the figure.

If the teeth of wheels and the leaves of pinions be formed according to the directions already given, they will act upon each other, not only with uniform force, but alſo without friction. The one tooth rolls upon the other, and neither ſlides nor rubs to ſuch a degree as to retard the wheels, or wear their teeth. But as it is impoſſible in practice to give that perfect curvature to the acting faces of the teeth which theory requires, a certain quantity of friction will remain after every precaution has been taken in the formation of the communicating parts. This friction may be removed, or at leaſt greatly diminiſhed, in the following manner.

If, inſtead of fixing the circular teeth, as in fig. 13, to the wheel DRE, they are made to move upon axles or ſpindles fixed in the circumference of the wheel, all the friction will be taken away except that which ariſes from the motion of the cylindrical tooth upon its axis. The advantages which attend this mode of conſtruction are many and obvious. The cylindrical teeth may be formed by a turning-lathe with the greateſt accuracy; the curve required for the teeth of the large wheel is eaſily traced; the preſſure and motion of the wheels will be uniform; and the teeth are not ſubject to wear, becauſe whatever friction remains is almoſt wholly removed by the revolution of the cylindrical ſpokes about their axes. The reader will alſo obſerve, that this improvement may be moſt eaſily introduced when the ſmall wheel has the form of a trundle or lantern; and that it may be adopted in caſes where lanterns could not be conveniently uſed. It however can only be adopted where the machinery is large. For ſmall works, the teeth of the pinion or ſmall wheel ſhould be rectilineal, and thoſe of the large wheel epicycloidal.

II. Having hitherto ſuppoſed, that the mutual action of the teeth does not commence till they arrive at the line of centres, let us now attend a little to the form which muſt be given them, when the whole of the action is carried on before they reach the line of centres, or when it is completed a very little below this line. This mode of action is not ſo advantageous as that which we have been conſidering, and ſhould, if poſſible, always be avoided. It is evident that the tooth of the wheel acts upon the leaf of the pinion before they arrive at the line of centres, that it quits the leaf when they reach this line, and that the tooth works deeper and deeper between the leaves of the pinion the nearer it comes to the line of centres. From this laſt circumſtance a conſiderable quantity of friction ariſes, becauſe the tooth does not, as before, *roll* upon the leaf, but *ſlides* upon it; and from the ſame cauſe the pinion ſoon becomes foul, as the duſt which lies upon the acting faces of the leaves is puſhed into the hollows between them. One advantage, however, attends this mode of action, for it allows us to make the teeth of the large wheel rectilineal, and thus renders the labour of the mechanic leſs, and the accuracy of his work greater, than if they had been of a curvilineal form. If the teeth therefore of the wheel are made rectilineal, having their ſurfaces directed to the wheel's centre, the acting faces of the leaves muſt be epicycloids formed by a generating circle, whoſe diameter is equal to the ſum of the radius of the wheel, added to the depth of one of its teeth, rolling upon the circumference of the pinion. But if the teeth of the wheel and the leaves of the pinion are made curvilineal, the acting faces of the teeth of the wheel muſt be portions of an interior epicycloid formed by any generating circle rolling within the concave ſuperficies of the large circle; and the acting faces of the pinion's leaves muſt be portions of an exterior epicycloid produced by rolling the ſame generating circle upon the convex circumference of the pinion.

When the teeth of the large wheel are cylindrical ſpindles either fixed or moveable upon their axes, an exterior epicycloid muſt be formed like DNM in fig. 13. pl. XXXII, by a generating circle whoſe radius is AC, rolling upon the convex circumference FCK, AC being in this caſe the diameter of the wheel, and FCK the circumference of the pinion. By means of this epicycloid a curve OPT muſt be formed as before deſcribed, which will be the proper curvature for the acting faces of the leaves of the pinion, when the teeth of the wheel are cylindrical. The relative diameter of the wheel and pinion, when the number of teeth in each is known, may be found by the ſame theorems which were given for the firſt mode of action, with this difference only, that in this caſe the radius of the wheel is reckoned from its centre to the extremity of its teeth, and the radius of the pinion from its centre to the bottom of its leaves.

III. The third way in which one wheel may drive another, is when the action is partly carried on before the acting teeth arrive at the line of centres, and partly after they have paſſed this line.

This mode of action, which is repreſented in fig. 5, plate XXXI, is a combination of the two firſt modes, and conſequently partakes of the advantages and diſadvantages of each. It is evident from the figure that the portion *e k* of the tooth acts upon the part *b c* of the leaf till they reach the line of centres AB (B the centre of the wheel is here alſo omitted in the figure), and that the part *e d* of the tooth acts upon the portion *b a* of the leaf after they have paſſed this line. It follows, therefore, that the acting parts *e h* and *b c* muſt be formed according to the directions given for the firſt mode of action, and that the remaining parts *e d*, *b a*, muſt have that curvature which the ſecond mode of action requires; conſequently *e h* ſhould be part of an interior epicycloid formed by any generating circle rolling on the concave circumference *m n* of the wheel, and the correſponding part *b c* of the leaf ſhould be part of an exterior epicycloid formed by the ſame generating circle rolling upon *b* EO, the convex circumference of the pinion: the remaining part *c d* of the tooth ſhould be a portion of an exterior epicycloid, engendered by any generating circle rolling upon *e* L, the concave ſuperficies of the wheel; and the correſponding part *b a* of the leaf ſhould be part of an interior epicycloid deſcribed by the ſame generating circle, rolling along the concave ſide *b* EO of the pinion. As it would be extremely troubleſome, however, to give this double curvature to the acting faces of the teeth, it will be proper to uſe a generating circle, whoſe diameter is equal to the radius of the wheel BC, for deſcribing the interior epicycloid *e h* and the exterior one *b c*, and a generating circle, whoſe diameter is equal to AC, the radius of the pinion, for deſcribing the interior epicycloid *b a*, and the exterior one *e d*. In this caſe the two interior epicycloids *e h*, *b a*, will be ſtraight lines tending to the centres B and A*, and the labour of the mechanic will by this means be greatly abridged.

In order to find the relative diameters of the wheel and pinion, when the number of teeth in the one and the number of leaves in the other are given, and when the diſtance of their centres is alſo given, and the ratio of ES to CS, let *a* be the number of teeth in the wheel, *b* the number of leaves in the pinion, *c* the diſtance of the pivots A, B, and let *m* be to *n* as ES to CS, then the arch ES, or the angle SAE, will be equal to $\frac{360^\circ}{b}$; and LD, or the angle LBD, will be equal to $\frac{360^\circ}{a}$. But as ES : CS :: *m* : *n*; conſequently LD : LC :: *m* : *n*, and $LC = \frac{LD \times n}{m}$; but LD is equal to $\frac{360^\circ}{a}$, therefore by ſubſtitution we have $LC = \frac{360 \times n}{a m}$.

Now, in the triangle APB, AB is known, and also PB, which is the coſine of the angle ABD, PC being perpendicular to DB, AP therefore may be found by plain trigonometry. The point P marks out the parts of the tooth D and the leaf SP where they commence their action; and the point I marks out the parts where their mutual action ceaſes*; AP therefore is the proper radius of the pinion, and BI the proper radius of the wheel, the parts of the tooth L without the point I, and of the leaf SP without the point P being ſuperfluous. Now, to find BI, we have ES : CS :: $m:n$, conſequently CS $=\frac{\text{ES}\times n}{m}$; but ES was formerly ſhewn to be equal to $\frac{360}{b}$, therefore, CS $=\frac{360\times n}{b\,m}$. Now the arch ES, or angle EAS, being equal to $\frac{360}{b}$, and CS, or the angle CAS, being equal to $\frac{360\times n}{b\,m}$, their difference EC, or the angle EAC, will be equal to $\frac{360}{b}-\frac{360\times n}{b\,m}$, or $=\frac{360^\circ\times(m-n)}{b\,m}$. The angle EAC being thus found, the triangle EAB, or IAB, which is nearly equal to it, is known, becauſe AB is given, and likewiſe AI, which is equal to the coſine of the angle IAB, AC being radius, and AIC being a right angle; conſequently IB the radius of the wheel may be found by trigonometry. It was formerly ſhewn that AC, the radius of what is called the primitive pinion, was equal to $\frac{c\,b}{a+b}$, and that BC, the radius of the primitive wheel, was equal to $\frac{\text{AC}\times a}{b}$. If then we ſubtract AC or AS from AP, we ſhall have the quantity SP, which muſt be added to the radius of the primitive pinion, and if we take the difference of BC (or BL) and DE, the quantity LE will be found, which muſt be added to the radius of the primitive wheel. We have all along ſuppoſed that the wheel drives the pinion, and have given the proper form of the teeth upon this ſuppoſition. But when the pinion drives the wheel, the form which was given to the teeth of the wheel, in the firſt caſe, muſt in this be given to the leaves of the pinion; and the ſhape which was formerly given to the leaves of the pinion muſt now be transferred to the teeth of the wheel.

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* Traité des Epicycloids, par M. De La Hire. Prop. V.

Another form for the teeth of wheels, different from any which we have mentioned, has been often recommended. A perfect uniformity of action may be ſecured, by making the acting faces of the teeth involutes of the wheel's circumference. Thus, in pl. XXXV, fig. 1. let AB be a portion of the wheel on which the tooth is to be fixed; and let A *p m* be a thread wrapped round its circumference, having a loop-hole at its extremity *a*. In this loop-hole fix the pin *a*, and with it deſcribe the curve or *involute*, *a b c d e k*, by unwrapping the thread gradually from the circumference A *p m*. This curve will be the proper form for the teeth of a wheel whoſe diameter is AB. As this form admits of ſeveral teeth to be acting at the ſame time (twice the number that can be admitted in M. De la Hire's method), the preſſure is divided among ſeveral teeth, and the quantity upon any one of them is ſo diminiſhed, that thoſe dints and impreſſions which they unavoidably make upon each other are partly prevented.

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* The letter L marks the interſection of the line BL with the arch *e m*, and the letter E the interſection of the arch *b* O with the upper ſurface of the leaf *m*. The letters D and S correſpond with L and B reſpectively, and P with I.

This form however, which we have before mentioned (vol. I. art. 147.), is only a modification of the general principle; as an involute may be reckoned, and indeed is called, by De la Hire, the laſt of the exterior epicycloids.

The involute *a b c d*, &c. may alſo be produced by an epicycloidal motion; for, ſince the circumference of a generating circle, whoſe centre is infinitely diſtant, muſt be a ſtraight line, we may form the involute *a b c*, by making a ſtraight ruler roll upon the circumference of the circle to be evolved. In fig. 1. let *a n* be a ſtraight ruler at whoſe extremity is fixed the pin *m*, and let the point of the pin be placed upon the point *m* of the circle, then by rolling the ſtraight ruler upon the circular baſe, ſo that the point in which it touches the circle may move gradually from *m* towards B, the curve *m n* will be generated exactly ſimilar to the involute *a b c*, &c.

As nothing can be of greater importance to the practical mechanic, than to have a method of drawing epicycloids with facility and accuracy; we give the following from Mr. Brewſter as an ample mechanical method. Take a piece of plain wood GH, fig. 2, pl. XXXV, and fix upon it another piece of wood E, having its circumference *m b* of the ſame curvature as the circular baſe upon which the generating circle AB is to roll. When the generating circle is large, the ſhaded ſegment B will be ſufficient: in any part of the circumference of this ſegment fix a ſharp-pointed nail *a*, ſloping in ſuch a manner that the diſtance of its point from the centre of the circle may be exactly equal to its radius; and faſten to the board GH a piece of thin braſs, or copper, or tin plate *a b*, diſtinguiſhed by the dotted lines. Place the ſegment B in ſuch a poſition that the point of the nail *a* may be upon the point *b*, and roll the ſegment towards G, ſo that the nail *a* may riſe gradually, and the point of contact between the two circular ſegments may advance towards *m*; the curve *a b* deſcribed upon the braſs plate will be an accurate exterior epicycloid. Remove, with a file, the part of the braſs on the left hand of the epicycloid, and the remaining concave arch or gage *a b* will be a pattern tooth, by means of which all the reſt may be eaſily formed. When an *interior epicycloid* is wanted, the concave ſide of its circular baſe muſt be uſed. The *cycloid*, which is uſeful in forming the teeth of *rack-work*, is generated preciſely in the ſame manner, with this difference only, that the baſe on which the generating circle rolls muſt be a ſtraight line.

Although, in general, it is neceſſary to give the proper curvature only to one ſide of the teeth, yet it may be proper to form both ſides with equal care, that the wheels may be able to move in a retrograde direction. This is particularly neceſſary when a reciprocating power is employed. In the caſe of a mill moving by the force of a ſingle-ſtroke ſteam-engine, the direction of the preſſure on the communicating parts of the machinery is changed twice every ſtroke. During the working-ſtroke, the teeth of the wheels which convey the motion from the beam to the machinery are acting with one ſide of their teeth; but during the returning ſtroke the wheels act with the other ſide of their teeth.

In order that the teeth may not embarraſs one another before their action commences, and that one tooth may begin to act upon its correſponding leaf of the pinion, before the preceding tooth has ceaſed to act upon the preceding leaf, the height, breadth, and diſtance of the teeth muſt be properly proportioned. For this purpoſe the pitch line or circumference of the wheel which is repreſented in pl. XXXI. fig. 5. by the dotted arches, muſt be divided into as many equal ſpaces as the number of teeth which the wheel is to carry. Divide each of theſe ſpaces into 16 equal parts; allow 7 of theſe for the greateſt breadth of the tooth, and 9 for the diſtance between each. If the wheel drives a trundle, each ſpace ſhould be divided into 7 equal parts, and 3 of theſe allotted for the thickneſs of the tooth, and $3\frac{2}{3}$ for the diameter of the cylindrical ſtave of the trundle. If each of the ſpaces already mentioned, or if the diſtance between the centres of each tooth, be divided into 3 equal parts, the height of the teeth muſt be equal to 2 of theſe. Theſe diſtances and heights, however, vary according to the mode of action which is employed. See Wolfii Opera Mathemat. tom. i. pa. 696. Belidor, Arch. Hydraulique, tom. i. chap. 2. Camus Courſe, tom. ii. and Brewſter's Ferguſon, vol. ii.

Such are ſome of the methods ſuggeſted by theory for the formation of the teeth of wheels; but it is ſeldom indeed that any of them are made uſe of by practical mechanics. Among them ſeveral methods are practiſed, almoſt every celebrated mill-wright or engineer having his favourite conſtruction; of theſe we ſhall only deſcribe one in this place; and that, being tolerably eaſy in application, allowing much ſtrength to the teeth, while it is pretty free from friction in compariſon with many practical methods, may ſometimes, perhaps, be ſafely adopted. Let A and B (fig. 11. pl. XXXV.) be two ſpur-wheels of different diameters, of which the cogs are intended to work into each other half the pitch. The dotted circular arcs GH, EF, touching each other between s and d, are the centre or pitch lines, from which the teeth are formed. If the teeth of both wheels are iron, as is generally the caſe in the firſt motions of works, thoſe teeth are then made nearly both of a ſize at the pitch line: but if the teeth of one be wood and the other iron, then the iron ones are made to have a good deal leſs pitch than the wooden ones; for then they are found to wear better. In the figure both are ſuppoſed of iron. Suppoſe the wheels to move from G towards H, and from E towards F, and that the ſides of the teeth at b, c, and d, e, are in contact. From b as a centre with a radius equal to $b\,p$, deſcribe the arcs $p\,d$, $l\,m$; from d as a centre with the ſame radius the arcs $k\,i$, $f\,g$, $c\,k$. Thus the ſame opening of the compaſſes, and a centre choſen where the wheels are in contact on the pitch line, will mark the contour of the upper part of a tooth of one wheel, and the lower part of a correſponding tooth of the other wheel: and by taking ſeveral centres on the two pitch lines, the various teeth may be formed. To prevent the cogs from *bottoming*, as the workmen call it, let the lower part $r\,e$ of one tooth be made rather longer than the upper part $p\,d$ of the other which is to play into it. The way in which cogs thus conſtructed will work into one another may be underſtood by conſidering the motion of two of them, n and o for example: when they firſt come into contact, they will appear as at the curve $x\,b\,P\,z$; when they arrive at Q the ſame ſides will appear as in the dotted lines there repreſented; and when the ſame arrive at RS, they are in contact on their middle points.

In bevel work (ſee fig. 7, pl. III.) when this method of forming the teeth is adopted, the radii $h\,y$, $g\,y$, of the wheels muſt not be taken as thoſe of the ſpur-wheel; but drawing a line through y perpendicular to $x\,y$, till it meets $x\,g$, and $x\,h$, produced, the ſegments of that line intercepted between y, and the produced lines $x\,g$, $x\,h$, muſt be uſed as the radii of the ſpur-wheels, and the other part of the conſtruction will be as above. The line through y drawn perpendicular to $x\,y$, is called by mill-wrights *ſquare of the bevel*. For more on the ſubject of bevel geer, conſult the introductory part of this volume. And for Mr. Maudſlay's contrivance for *cutting* teeth of wheels, ſee the article TURNING.

TELEGRAPH (derived from τηλε and γραφω), is the name very properly given to an inſtrument, by means of which information may be almoſt inſtantaneouſly conveyed to a conſiderable diſtance.

The telegraph, though it has been generally known and uſed by the moderns only for a few years, is by no means a modern invention. There is reaſon to believe that amongſt the Greeks there was ſome ſort of telegraph in uſe. The burning of Troy was certainly known in Greece very ſoon after it happened, and before any perſon had returned from thence. Now that was altogether ſo tedious a piece of buſineſs, that conjecture never could have ſupplied the place of information. A Greek play begins with a ſcene, in which a watchman deſcends from the top of a tower in Greece, and gives the information that Troy was taken. "I have been looking out theſe ten years (ſays he) to ſee when that would happen, and this night it is done." Of the antiquity of a mode of conveying intelligence quickly to a great diſtance this is certainly a proof.

The Chineſe, when they ſend couriers on the great canal, or when any great man travels there, make ſignals by fire from one day's journey to another, to have every thing prepared; and moſt of the barbarous nations uſed formerly to give the alarm of war by fires lighted on the hills or riſing grounds.

Polybius calls the different inſtruments uſed by the ancients for communicating information πυρσειαι, *pyrſiæ*, becauſe the ſignals were always made by means of fire. At firſt they communicated information of events merely by torches; but this method was of little uſe, becauſe it was neceſſary before-hand to fix the meaning of every particular ſignal. Now as events are exceedingly various, it was impoſſible to expreſs the greater number of them by any premeditated contrivance. It was eaſy, for inſtance, to expreſs by ſignals that a fleet had arrived at ſuch a place, becauſe this had been foreſeen, and ſignals accordingly had been agreed upon to denote it; but an unexpected revolt, a murder, and ſuch accidents, as happen but too often, and require an immediate remedy, could not be communicated by ſuch ſignals; becauſe to foreſee them was impoſſible.

A new method was invented by Cleoxenus (others ſay by Democritus), and very much improved by Polybius, as he himſelf informs us. He deſcribes this method as follows: Take the letters of the (Greek) alphabet, and divide them into five parts, each of which will conſiſt of five letters, except the laſt diviſion, which will have only four. Let theſe be fixed on a board in five columns. The man who is to give the ſignals is then to begin by holding up two torches, which he is to keep aloft till the other party has alſo ſhewn two. This is only to ſhew that both ſides are ready. Theſe firſt torche are then withdrawn. Both parties are provided with boards, on which the letters are diſpoſed as formerly deſcribed. The perſon then who gives the ſignal is to hold up torches on the left to point out to the other party from what column he ſhall take the letters as they are pointed out to him. If it is to be from the firſt column, he holds up one torch; if from the ſecond, two; and ſo on for the others. He is then to hold up torches on the right, to denote the particular letter of the column that is to be taken. All this muſt have been agreed on before-hand. The man who gives the ſignals muſt have an inſtrument (διοπτραν), conſiſting of two tubes, and ſo placed as that, by looking through one of them, he can ſee only the right ſide, and through the other only the left, of him who is to anſwer. The board muſt be ſet up near this inſtrument; and the ſtation on the right and left muſt be ſurrounded with a wall (παραπεφραχθαι), ten feet broad, and about the height of a man, that the torches raiſed above it may give a clear and ſtrong light, and that when taken down they may be completely concealed. Let us now ſuppoſe that this information is to be communicated—*A number of the auxiliaries, about a hundred, have gone over to the enemy.* In the firſt place, words muſt be choſen that will convey the information in the feweſt letters poſſible; as, *A hundred Cretans have deſerted*, Κρετες εκατον αφ' ημων ηυτομολησαν. Having written down this ſentence, it is conveyed in this manner. The firſt letter is a K, which is in the ſecond column; two torches are therefore to be raiſed on the left hand to inform the perſon who receives the ſignals to look into that particular column. Then five torches are to be held up on the right, to mark the letter *k*, which is the left in the column. Then four torches are to be held up on the left to point out the ρ (*r*), which is in the fourth column, and two on the right to ſhow that it is the ſecond letter of that column. The other letters are pointed out in the ſame manner.—Such was the *pyrſia* or telegraph recommended by Polybius.

But neither this nor any other method mentioned by the ancients ſeems ever to have been brought into general uſe: nor does it appear that the moderns had thought of ſuch a machine as a telegraph till the year 1663, when the marquis of Worceſter, in his Century of Inventions, affirmed that he had diſcovered "a method by which, at a window, as far as eye can diſcover black from white, a man may hold diſcourſe with his correſpondent, without noiſe made or notice taken; being according to occaſion given, or means afforded, *in re nata*, and no need of proviſion beforehand; though much better if foreſeen, and courſe taken by mutual conſent of parties." This could be done only by means of a telegraph, which in the next ſentence is declared to have been rendered ſo perfect, that by means of it the correſpondence could be carried on " by night as well as by day, though as dark as pitch is black."

Dr. Hooke, whoſe genius as a mechanical inventor was perhaps never ſurpaſſed, delivered a " Diſcourſe to the Royal Society, May 21, 1684, ſhewing a way how to communicate one's mind at great diſtances." In this diſcourſe, he aſſerted the poſſibility of conveying intelligence from one place to another at the diſtance of 30, 40, 100, 120, &c. miles, " in as ſhort a time almoſt as a man can write what he would have ſent." He takes to his aid the then recent invention of the teleſcope, and explains the method by which characters expoſed at one ſtation may be rendered plain and diſtinguiſhable at the others. He directs, " Firſt, for the ſtations; if they be far diſtant, it will be neceſſary that they ſhould be high, and lie expoſed to the ſky; that there be no higher hill, or part of the earth beyond them, that may hinder the diſtinctneſs of the characters that are to appear dark, the ſky beyond them appearing white: by which means alſo the thick and vaporous air near the ground will be paſſed over and avoided." " Next, the height of the ſtations is advantageous, upon the account of the refractions or inflections of the air." " Next, in chooſing of theſe ſtations, care muſt be taken, as near as may be, that there be no hill that interpoſes between them, that is almoſt high enough to touch the viſible ray; becauſe in ſuch caſes the refraction of the air of that hill will be very apt to diſturb the clear appearance of the object." " The next thing to be conſidered is, what teleſcopes will be neceſſary for ſuch ſtations." " One of theſe teleſcopes muſt be fixed at each extreme ſtation, and two of them in each intermediate; ſo that a man for each glaſs, ſitting and looking through them, may plainly diſcover what is done in the next adjoining ſtation, and with his pen write down on paper the characters there expoſed in their due order; ſo that there ought to be two perſons at each extreme ſtation, and three at each intermediate; ſo that, at the ſame time, intelligence may be conveyed forwards and backwards." " Next, there muſt be certain times agreed on, when the correſpondents are to expect; or elſe there muſt be ſet at the top of the pole, in the morning, the hour appointed by either of the correſpondents for acting that day: if the hour be appointed, pendulum clocks may adjuſt the moment of expectation and obſerving." " Next, there muſt be a convenient apparatus of characters, whereby to communicate any thing with great eaſe, diſtinctneſs, and ſecrecy. And thoſe muſt be either day characters or night characters." The day characters "may all be made of three ſlit deals:" the night characters "may be made with links, or other lights, diſpoſed in a certain order." The doctor invented 24 ſimple characters, each conſtituted of right lines, for the letters of the alphabet; and ſeveral ſingle characters, made up of ſemicircles, for whole ſentences. He recommended that three very long maſts or poles ſhould be placed vertically, and joined at top by one ſtrong horizontal beam; that a large ſcreen ſhould be placed at one of the upper corners of this frame, behind which all the deal-board characters ſhould hang, and by the help of proper cords ſhould quickly be drawn forwards to be expoſed, and then drawn back again behind the ſcreen. "By theſe means," ſays the doctor, "all things may be made ſo convenient that the ſame character may be ſeen at Paris, within a minute after it hath been expoſed at London, and the like in proportion for greater diſtances; and that the characters may be expoſed ſo quick after one another, that a compoſer ſhall not much exceed the expoſer in ſwiftneſs." Among the uſes of this contrivance, the inventor ſpecifies theſe: "The firſt is for cities or towns beſieged; and the ſecond for ſhips upon the ſea; in both which caſes it may be practiſed with great certainty, ſecurity, and expedition." The whole of Dr. Hooke's paper was publiſhed in Derham's collection of his *Experiments and Obſervations*; from which it appears, that he had brought the telegraph to a ſtate of far greater maturity and perfection than M. Amontons, who attempted the ſame thing about the year 1702; and indeed to a ſtate little inferior to ſeveral which have been propoſed during the laſt twenty years.

It was not, however, till the French revolution that the telegraph was applied to uſeful purpoſes. Whether M. Chappe, who is ſaid to have invented the telegraph firſt uſed by the French about the end of 1793, knew any thing of Hooke's or of Amonton's invention, it is impoſſible to ſay; but his telegraph was conſtructed on principles nearly ſimilar. The manner of uſing this telegraph was as follows: at the firſt ſtation, which was on the roof of the palace of the Louvre at Paris, M. Chappe, the inventor, received in writing, from the committee of public welfare, the words to be ſent to Liſle, near which the French army at that time was. An upright poſt was erected on the Louvre, at the top of which were two tranverſe arms, moveable in all directions by a ſingle piece of mechaniſm, and with inconceivable rapidity. He invented a number of poſitions for theſe arms, which ſtood as ſigns for the letters of the alphabet; and theſe, for the greater celerity and ſimplicity, he reduced in number as much as poſſible. The grammarian will eaſily conceive that ſixteen ſigns may amply ſupply all the letters of the alphabet, ſince ſome letters may be omitted, not only without detriment, but with advantage. Theſe ſigns, as they were arbitrary, could be changed every week; ſo that the ſign of B for one day might be the ſign of M the next; and it was only neceſſary that the perſons at the extremities ſhould know the key. The intermediate operators were only inſtructed generally in theſe ſixteen ſignals; which were ſo diſtinct, ſo marked, ſo different the one from the other, that they were eaſily remembered. The conſtruction of the machine was ſuch, that each ſignal was uniformly given in preciſely the ſame manner at all times: it did not depend on the operator's manual ſkill; and the poſition of the arm could never, for any one ſignal, be a degree higher or a degree lower, its movement being regulated mechanically.

M. Chappe having received at the Louvre the ſentence to be conveyed, gave a known ſignal to the ſecond ſtation, which was Mont Martre, to prepare. At each ſtation there was a watch-tower, where teleſcopes were fixed, and the perſon on watch gave the ſignal of preparation which he had received, and this communicated ſucceſſively through all the line, which brought them all into a ſtate of readineſs. The perſon at Mont Martre then received, letter by letter, the ſentence from the Louvre, which he repeated with his own machine; and this was again repeated from the next height, with inconceivable rapidity, to the final ſtation at Liſle.

The firſt deſcription of the telegraph was brought from Paris to Frankfort on the Maine by a former member of the parliament of Bourdeaux, who had ſeen that which was erected on the mountain of Belville. As given by Dr. Hutton from ſome of the Engliſh papers, it is as follows. AA is a beam or maſt of wood placed upright on a riſing ground (fig. 1. pl. XXXIII.), which is about fifteen or ſixteen feet high. BB is a beam or balance moving upon the centre AA. This balance-beam may be placed vertically or horizontally, or any how inclined, by means of ſtrong cords, which are fixed to the wheel D, on the edge of which is a double groove to receive the two cords. This balance is about eleven or twelve feet long, and nine inches broad, having at the ends two pieces of wood CC, which likewiſe turn upon angles by means of four other cords that paſs through the axis of the main balance, otherwiſe the balance would derange the cords; the pieces C are each about three feet long, and may be placed either to the right or left, ſtraight or ſquare, with the balance-beam. By means of theſe three the combination of movement is very extenſive, remarkably ſimple, and eaſy to perform. Below is a ſmall wooden gouge or hut, in which a perſon is employed to obſerve the movements of the machine. In the mountain neareſt to this, another perſon is to repeat theſe movements, and a third to write them down. The time taken up for each movement is twenty ſeconds; of which the motion alone is four ſeconds, the other 16 the machine is ſtationary. Two working models of this inſtrument were executed at Frankfort, and ſent by Mr. W. Playfair to the duke of York: and hence the plan and alphabet of the machine came to England.

Various experiments were in conſequence tried upon telegraphs in this country; and one was ſoon after ſet up by government in a chain of ſtations from the admiralty-office to the ſea-coaſt. It conſiſts of ſix octagon boards, each of which is poiſed upon an axis in a frame, in ſuch a manner that it can be either placed vertically, ſo as to appear with its full ſize to the obſerver at the neareſt ſtation, as in fig. 2. or it becomes inviſible to him by being placed horizontally, as in fig. 3. ſo that the narrow edge alone is expoſed, which narrow edge is from a diſtance inviſible. Fig. 2. is a repreſentation of this telegraph, with the parts all ſhut, and the machine ready to work. T, in the officer's cabin, is the teleſcope pointed to the next ſtation. Fig. 3. is a repreſentation of the machine not at work, and with the ports all open. The opening of the firſt port (fig. 2.) expreſſes *a*, the ſecond *b*, the third *c*, the fourth *d*, the fifth *e*, and the ſixth *f*, &c.

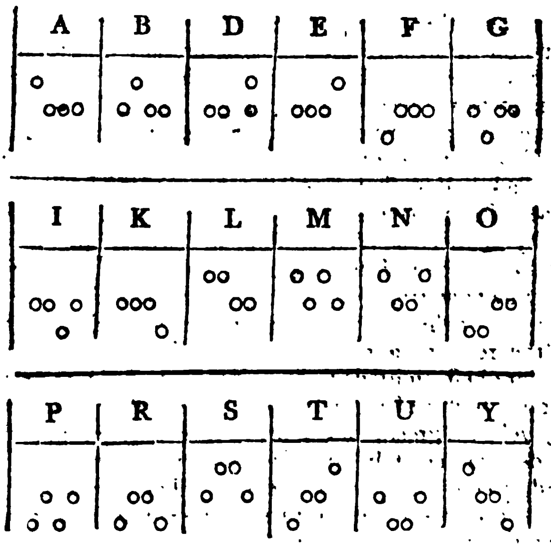
Six boards make 36 changes, by the moſt plain and ſimple mode of working; and they will make many more if more were neceſſary: but as the real ſuperiority of the telegraph over all other modes of making ſignals conſiſts in its making letters, we do not think that more changes than the letters of the alphabet, and the ten arithmetical cyphers, are neceſſary; but, on the contrary, that thoſe who work the telegraphs ſhould avoid communicating by words or ſigns agreed upon to expreſs ſentences; for that is the ſure method never to become expert at ſending unexpected intelligence accurately.

Several other telegraphs have been propoſed to remedy the defects to which the inſtrument is ſtill liable. The dial-plate of a clock would make an excellent telegraph, as it might exhibit 144 ſigns ſo as to be viſible at a great diſtance. A telegraph on this principle, with only ſix diviſions inſtead of twelve, would be ſimple and cheap, and might be raiſed 20 or 30 feet high above the building without any difficulty: it might be ſupported on one poſt, and therefore turn round, and the contraſt of colours would always be the ſame.

A very ingenious improvement of the telegraph has been propoſed in the Gentleman's Magazine. It conſiſts of a ſemicircle, to be properly elevated, and fixed perpendicularly on a ſtrong ſtand. The radius 12 feet; the ſemicircle conſequently ſomewhat more than 36. This is to be divided into 24 parts. Each of theſe will therefore compriſe a ſpace of 18 inches, and an arch of 7° 30′ on the circumference. Theſe 24 diviſions to be occupied by as many circular apertures of ſix inches diameter; which will leave a clear ſpace of ſix inches on each ſide between the apertures. Theſe apertures, beginning from the left, to denote the letters of the alphabet, omitting K, J conſonant, V, X, and Q, as uſeleſs for this purpoſe. There are then 21 letters. The four other ſpaces are reſerved for ſignals. The inſtrument to have an index moveable by a windlaſs on the centre of the ſemicircle, and having two tops, according as it is to be uſed in the day or night; one, a circular top of lacquered iron or copper, of equal diameter with the apertures (and which conſequently will eclipſe any of them againſt which it reſts); the other, a ſpear or arrow-ſhaped top, black, and highly poliſhed, which in ſtanding before any of the apertures in the day-time, will be diſtinctly viſible. In the night, the apertures to be reduced by a diaphragm fitting cloſe to each, ſo as to leave an aperture of not more than two inches diameter. The diaphragm to be of well-poliſhed tin; the inner rim lacquered black half an inch. All the apertures to be illuminated, when the inſtrument is uſed in the night-time, by ſmall lamps; to which, if neceſſary, according to circumſtances, convex lenſes may be added, fitted into each diaphragm, by which the light may be powerfully concentrated and increaſed. Over each aperture one of the five priſmatic colours leaſt likely to be miſtaken (the remaining two being leſs diſtinguiſhable, and not wanted, are beſt omitted) to be painted; and, in their natural order, on a width of eighteen inches and a depth of four, red, orange, yellow, green, blue; or, ſtill to heighten the contraſt, and render immediately ſucceſſive apertures more diſtinguiſhable, red, green, orange, blue, yellow. The whole inner circle beneath and between the apertures to be painted black.

When the inſtrument is to be uſed, the index to be ſet to the ſignal apertures on the right. All the apertures to be covered or dark when it begins to be uſed, except that which is to give the ſignal. A ſignal gun to be fired to appriſe the obſerver. If the index is ſet to the firſt aperture, it will denote that words are to be expreſſed; if to the ſecond, that figures; if to the third, that the figures ceaſe; and that the intelligence is carried on in words. When figures are to be expreſſed, the alternate apertures from the left are taken in their order, to denote from 1 to 10 incluſively; the ſecond from the right denotes 100; the fifth 1000. This order, and theſe intervals, are taken to prevent any confuſion in ſo peculiarly important an article of the intelligence to be conveyed.

Perhaps, however, none of the telegraphs hitherto offered to the public exceeds the following, either in ſimplicity, cheapneſs, or facility in working; and it might, perhaps, with a few trifling additions, be made exceedingly diſtinct. It is thus deſcribed in the *Repertory of Arts and Manufactures*: for a nocturnal telegraph, let there be four large patent reflectors, lying on the ſame plane, parallel to the horizon, placed on the top of an obſervatory. Let each of theſe reflectors be capable, by means of two winches, either of elevation or depreſſion to a certain degree. By elevating or depreſſing one or two of the reflectors, eighteen very diſtinct arrangements may be produced, as the following ſcheme will explain.



For the ſake of example, the above arrangements are made to anſwer to the moſt neceſſary letters of the alphabet; but alterations may be made at will, and a greater number of changes produced, without any addition to the reflectors. In the firſt obſervatory there need only be a ſet of ſingle reflectors; but in the others each reflector ſhould be double, ſo as to face both the preceding and ſubſequent obſervatory; and each obſervatory ſhould be furniſhed with two teleſcopes. The proper diameter of the reflectors, and their diſtance from each other, will be aſcertained by experience; and it muſt be obſerved, that each reflector, after every arrangement, muſt be reſtored to its place.

To convert this machine into a diurnal telegraph, nothing more is neceſſary than to inſert, in the place of the reflectors, gilt balls, or any other conſpicuous bodies.

Since theſe inventions were made public, telegraphs have been brought to ſo great a degree of perfection, that they now convey information ſpeedily and diſtinctly, and are ſo much ſimplified, that they can be conſtructed and maintained at little expence. The advantages too which reſult from their uſe are almoſt inconceivable. Not to ſpeak of the ſpeed with which information is communicated and orders given in time of war, by means of them, the whole kingdom could be prepared in an inſtant to oppoſe an invading enemy. A telegraph might be alſo uſed by commercial men to convey a commiſſion cheaper and ſpeedier than an expreſs can travel. An eſtabliſhment of telegraphs might be made like that of the poſt; and inſtead of being an expence, it would produce a revenue. Something of this kind has lately been ſet up to facilitate the intercourſe between Norwich and Yarmouth.

THERMOMETER, an inſtrument for meaſuring the degree of heat or cold in any body. The thermometer was invented about the beginning of the 15th century; but, like many other uſeful inventions, it has been found impoſſible to aſcertain to whom the honour of it belongs.

The firſt form of this inſtrument for meaſuring the degrees of heat and cold was the air-thermometer. It is a well-known fact that air expands with heat ſo as to occupy more ſpace than it does when cold, and that it is condenſed by cold ſo as to occupy leſs ſpace than when warmed, and that this expanſion and condenſation is greater or leſs according to the degree of heat or cold applied. The principle then on which the air-thermometer was conſtructed is very ſimple. The air was confined in a tube by means of ſome coloured liquor; the liquor roſe or fell according as the air became expanded or condenſed.

This inſtrument was extremely defective: for the air in the tube was not only affected by the heat and cold of the atmoſphere, but alſo by its weight.

The air being found improper for meaſuring with accuracy the variations of heat and cold according to the form of the thermometer which was firſt adopted, another fluid was propoſed about the middle of the 17th century by the Florentine academy. This fluid was ſpirit of wine, or alcohol, as it is now generally named. The alcohol being coloured, was incloſed in a very fine cylindrical glaſs tube previouſly exhauſted of its air, having a hollow ball at the lower end, and hermetically ſealed at the other end. The ball and tube are filled with rectified ſpirit of wine to a convenient height, when the weather is of a mean temperature, which may be done by inverting the tube into a veſſel of ſtagnant coloured ſpirit, under a receiver of the air-pump, or in any other way. When the thermometer is properly filled, the upper end is heated red-hot by a lamp, and then hermetically ſealed, leaving the included air of about $\frac{1}{7}$ of its natural denſity, to prevent the air which is in the ſpirit from dividing it in its expanſion. To the tube is applied a ſcale, divided from the middle into 100 equal parts, upwards and downwards.

As ſpirit of wine is capable of a very conſiderable degree of rarefaction and condenſation by heat and cold, when the heat of the atmoſphere increaſes the ſpirit dilates, and conſequently riſes in the tube; and when the heat decreaſes the ſpirit deſcends, and the degree or quantity of the motion is ſhown by a ſcale.

The ſpirit of wine thermometer was not ſubject to ſome of the inconveniences which attended the air-thermometer. In particular, it was not affected by variations in the weight of the atmoſphere: accordingly it ſoon came into general uſe among philoſophers. It was, at an early period, introduced into Britain by Mr. Boyle. To this inſtrument, as then uſed, there are, however, many objections. The liquor was of different degrees of ſtrength; and therefore different tubes filled with it, when expoſed to the ſame degree of heat, would not correſpond. There was alſo another defect; the ſcale which was adjuſted to the thermometer did not commence at any fixed point. The higheſt term was adjuſted to the great ſun-ſhine heats of Florence, which are too variable and undetermined; and frequently the workman formed the ſcale according to his own fancy. While the thermometer laboured under ſuch diſadvantages it could not be of general uſe.

To obtain ſome fixed unalterable point by which a determined ſcale might be diſcovered, to which all thermometers might be accurately adjuſted, was the ſubject which next drew the attention of philoſophers. Mr. Boyle, who ſeems at an early period to have ſtudied this ſubject with much anxiety, propoſed the freezing of the eſſential oil of anniſeeds as a convenient point for graduating thermometers; but this opinion he ſoon laid aſide. Dr. Halley next propoſed that thermometers ſhould be graduated in a deep pit under ground, where the temperature both in winter and ſummer is pretty uniform; and that the point to which the ſpirit of wine ſhould riſe in ſuch a ſubterraneous place ſhould be the point from which the ſcale ſhould commence. But this propoſal was evidently attended with ſuch inconveniences that it was ſoon abandoned. He made experiments on the boiling point of water, of mercury, and of ſpirit of wine; and he ſeems rather to give a preference to the ſpirit of wine. He objected to the freezing of water as a fixed point, becauſe he thought that it admitted conſiderable latitude.

It ſeems to have been reſerved to the genius of Newton to determine this important point, on which the accuracy and value of the thermometer depends. He choſe, as fixed, thoſe points at which water freezes and boils; the very points which the experiments of ſucceeding philoſophers have determined to be the moſt fixed and convenient. Senſible of the diſadvantages of ſpirit of wine, he tried another liquor which was homogeneous enough, capable of a conſiderable rarefaction, about 15 times greater than ſpirit of wine. This was linſeed oil. It has not been obſerved to freeze even in very great colds, and it bears a heat about four times that of water before it boils. With theſe advantages it was made uſe of by Newton, who diſcovered by it the comparative degree of heat for boiling water, melting wax, boiling ſpirit of wine, and melting tin; beyond which it does not appear that this thermometer was applied. The method he uſed for adjuſting the ſcale of this oil-thermometer was as follows: ſuppoſing the bulb, when immerged in thawing ſnow, to contain 10,000 parts, he found the oil expand by the heat of the human body ſo as to take up $\frac{1}{39}$th more ſpace, or 10,256 ſuch parts; and by the heat of water boiling ſtrongly 10,725; and by the heat of melting tin 11,516. So that reckoning the freezing point as a common limit between heat and cold, he began his ſcale there, marking it 0, and the heat of the human body he made 12°; and conſequently, the degrees of heat being proportional to the degrees of rarefaction, or 256 : 725 : : 12 : 34, this number 34 will expreſs the heat of boiling water; and by the ſame rule, 72 that of melting tin. This thermometer was conſtructed in 1701.

To the application of oil as a meaſure of heat and cold there are inſuperable objections. It is ſo viſcid, that it adheres too ſtrongly to the ſides of the tube. On this account it aſcends and deſcends too ſlowly in caſe of a ſudden heat or cold. In a ſudden cold, ſo great a proportion remains adhering to the ſides of the tube after the reſt has ſubſided, that the ſurface appears lower than the correſponding temperature of the air requires. An oil-thermometer is therefore not a proper meaſure of heat and cold.

All the thermometers hitherto propoſed were liable to many inconveniences, and could not be conſidered as exact ſtandards for pointing out the various degrees of temperature. This led Reaumur to attempt a new one, an account of which was publiſhed in the year 1730, in the Memoirs of the Academy of Sciences. This thermometer was made with ſpirit of wine. He took a large ball and tube, the dimenſions and capacities of which were known: he then graduated the tube, ſo that the ſpace from one diviſion to another might contain 1000th part of the liquor; the liquor containing 1000 parts when it ſtood at the freezing point. He adjuſted the thermometer to the freezing point by an artificial congelation of water: then putting the ball of his thermometer and part of the tube into boiling water, he obſerved whether it roſe 80 diviſions: if it exceeded theſe, he changed his liquor, and by adding water, lowered it, till upon trial it ſhould juſt riſe 80 diviſions; or if the liquor, being too low, fell ſhort of 80 diviſions, he raiſed it by adding rectified ſpirit to it. The liquor thus prepared ſuited his purpoſe, and ſerved for making a thermometer of any ſize, whoſe ſcale would agree with his ſtandard.

This thermometer was far from being perfect. As the bulbs were three or four inches in diameter, the ſurrounding ice would be melted before its temperature could be propagated to the whole ſpirits in the bulb, and conſequently the freezing point would be marked higher than it ſhould be. Dr. Martine accordingly found, that inſtead of coinciding with the 32d degree of Fahrenheit, it correſponded with the 34th, or a point a little above it. Reaumur committed a miſtake alſo reſpecting the boiling point; for he thought that the ſpirit of wine, whether weak or ſtrong, when immerged in boiling water, received the ſame degree of heat with the boiling water. But it is well known that highly-rectified ſpirit of wine cannot be heated much beyond the 175th degree of Fahrenheit, while boiling water raiſes the quickſilver 37 degrees higher. There is another thermometer that goes by the name of *Reaumur's*, which ſhall be afterwards deſcribed.

At length a different fluid was propoſed, by which thermometers could be made free from moſt of the defects hitherto mentioned. This fluid was mercury, and ſeems firſt to have occurred to Dr. Halley in the laſt century; but was not adopted by him, on account of its having a ſmaller degree of expanſibility than the other fluids uſed at that time. Boerhaave ſays that the mercurial thermometer was firſt conſtructed by Olaus Roemer; but the honour of this invention is generally given to Fahrenheit of Amſterdam, who preſented an account of it to the Royal Society of London in 1724.

Mercury is far ſuperior to alcohol and oil, and is much more manageable than air. 1. As far as the experiments already made can determine, it is of all the fluids hitherto employed in the conſtruction of thermometers that which meaſures moſt exactly equal differences of heat by equal differences of its bulk: its dilatations are in fact very nearly proportional to the augmentations of heat applied to it. 2. Of all liquids it is the moſt eaſily freed from air. 3. It is fitted to meaſure high degrees of heat and cold. It ſuſtains a heat of 600° of Fahrenheit's ſcale, and does not congeal till it falls 39 or 40 degrees below 0. 4. It is the moſt ſenſible of any fluid to heat and cold, even air not excepted. Count Rumford found that mercury was heated from the freezing to the boiling point in 58 ſeconds, while water took two minutes 13 ſeconds, and common air 10 minutes and 17 ſeconds. 5. Mercury is a homogeneous fluid, and every portion of it is equally dilated or contracted by equal variations of heat. Any one thermometer made of pure mercury is, *cæteris paribus*, poſſeſſed of the ſame properties with every other thermometer made of pure mercury. Its power of expanſion is indeed about ſix times leſs than that of ſpirit of wine, but it is great enough to anſwer moſt of the purpoſes for which a thermometer is wanted.

The fixed points which are now univerſally choſen for adjuſting thermometers to a ſcale, and to one another, are the boiling and freezing water points. The boiling water point, it is well known, is not an invariable point, but varies ſome degrees according to the weight and temperature of the atmoſphere. In an exhauſted receiver, water will boil with a heat of 98° or 100°; whereas in Papin's digeſter it will acquire a heat of 412°. Hence it appears that water will boil at a lower point, according to its height in the atmoſphere, or to the weight of the column of air which preſſes upon it. In order to enſure uniformity therefore in the conſtruction of thermometers, it is now agreed that the bulb of the tube be plunged in the water when it boils violently, the barometer ſtanding at 30 Engliſh inches (which is its mean height round London), and the temperature of the atmoſphere 55°. A thermometer made in this way, with its boiling point at 212°, is called by Dr. Horſley *Bird's Fahrenheit*, becauſe Mr. Bird was the firſt perſon who attended to the ſtate of the barometer in conſtructing thermometers.

As artiſts may be often obliged to adjuſt thermometers under very different preſſures of the atmoſphere, philoſophers have been at pains to diſcover a general rule which might be applied on all occaſions. M. de Luc, in his *Recherches ſur les Mod. de l'Atmoſphere*, has given, from a ſeries of experiments, an equation for the allowance on account of this difference, in Paris meaſure, which has been verified by Sir George Schuckburgh; alſo Dr. Horſley, Dr. Maſkelyne, and Sir George Schuckburgh, have adapted the equation and rules to Engliſh meaſures, and have reduced the allowances into tables for the uſe of the artiſt. Dr. Horſley's rule, deduced from De Luc's, is this:

$$\frac{99}{8990000}\log.z-92\cdot864=h.$$

where h denotes the height of a thermometer plunged in boiling water, above the point of melting ice, in degrees of Bird's Fahrenheit, and z the height of the barometer in 10ths of an inch. From this rule he has computed the following table for finding the heights to which a good Bird's Fahrenheit will riſe when plunged in boiling water, in all ſtates of the barometer, from 27 to 31 Engliſh inches; which will ſerve, among other uſes, to direct inſtrument-makers in making a true allowance for the effect of the variation of the barometer, if they ſhould be obliged to finiſh a thermometer at a time when the barometer is above or below 30 inches; though it is beſt to fix the boiling point when the barometer is at that height.

Equation of the Boiling Point.

Barometer.	Equation.	Difference.
31·0	+ 1·57	0·78
30·5	+ 0·79	0·79
30·0	0.00	0·80
29·5	— 0·80	0·82
29·0	— 1·62	0·83
28·5	— 2·45	0·85
28·0	— 3·31	0·86
27·5	— 4·16	0·88
27·0	— 5·04	

The numbers in the firſt column of this table expreſs heights of the quickſilver in the barometer in Engliſh inches and decimal parts: the ſecond column ſhows the equation to be applied, according to the ſign prefixed, to 212° of Bird's Fahrenheit, to find the true boiling point for every ſuch ſtate of the barometer. The boiling point for all intermediate ſtates of the barometer may be had with ſufficient accuracy, by taking proportional parts, by means of the third column of differences of the equation. See Phil. Tranſ. lxiv. art. 30.; alſo Dr. Maſkelyne's Paper, vol. lxiv. art. 20.

Sir George Schuckburgh alſo has given the following general table for the uſe of artiſts in conſtructing the thermometer, both according to his own obſervations and thoſe of M. de Luc.

Height of the Barometer.	Correct. of the boiling point.	Difference.	Correct. accord. to M. de Luc.	Difference.
	°		°	
26·0	— 7·09	·91	— 6·83	·90
26·5	— 6·18	·91	— 5·93	·89
27·0	— 5·27	·90	— 5·04	·88
27·5	— 4·37	·89	— 4·16	·87
28·0	— 3·48	·89	— 3·31	·86
28·5	— 2·59	·87	— 2·45	·83
29·0	— 1·72	·87	— 1·62	·82
29·5	— 0·85	·85	— 0·80	·80
30·0	0·00	·85	0·00	·79
30·5	+ 0·85	·84	+ 0·79	·78
31·0	+ 1·69		+ 1·57	

The Royal Society, fully appriſed of the importance of adjuſting the fixed points of thermometers, appointed a committee of ſeven gentlemen to conſider of the beſt method for this purpoſe; and their report is publiſhed in the Phil. Tranſ. vol. lxvii. part ii. art. 37.

They obſerved, that though the boiling point be placed ſo much higher on ſome of the thermometers now made than on others, yet this does not produce any conſiderable error in the obſervations of the weather, at leaſt in this climate; for an error of 1¼° in the poſition of the boiling point will make an error only of half a degree in the poſition of 92°, and of not more than a quarter of a degree in the point of 62°. It is only in nice experiments, or in trying the heat of hot liquors, that this error in the boiling point can be of much importance.

In adjuſting the freezing as well as the boiling point, the quickſilver in the tube ought to be kept of the ſame heat as that in the ball. When the freezing point is placed at a conſiderable diſtance from the ball, the pounded ice ſhould be piled to ſuch a height above the ball, that the error which can ariſe from the quickſilver in the remaining part of the tube, not being heated equally with that in the ball, ſhall be very ſmall, or the obſerved point muſt be corrected on that account according to the following table:

Heat of the Air.	Correction.
42°	·00087
52	·00174
62	·00261
72	·00348
82	·00435

The correction in this table is expreſſed in 1000th parts of the diſtance between the freezing point and the ſurface of the ice: *e. g.* if the freezing point ſtands ſeven inches above the ſurface of the ice, and the heat of the room is 62, the point of 32° ſhould be placed 7 × ·00261, or ·018 of an inch lower than the obſerved point. A diagonal ſcale will facilitate this correction.

The committee obſerve, that in trying the heat of liquors, care ſhould be taken that the quickſilver in the tube of the thermometer be heated to the ſame degree as that in the ball; or if this cannot be done conveniently, the obſerved heat ſhould be corrected on that account; for the manner of doing which, and a table calculated for this purpoſe, we muſt refer to their excellent report in the Phil. Tranſ. vol. lxvii. part ii. art. 37.

With regard to the choice of tubes, they ought to be exactly cylindrical. But though the diameter ſhould vary a little, it is eaſy to manage that matter in the manner propoſed by the Abbé Nollet, by making a ſmall portion of the quickſilver, *e. g.* as much as fills up an inch or half an inch, ſlide backward and forward in the tube; and thus to find the proportions of all its inequalities, and from thence to adjuſt the diviſions to a ſcale of the moſt perfect equality. The capillary tubes are preferable to others, becauſe they require ſmaller bulbs, and they are alſo more ſenſible, and leſs brittle. The moſt convenient ſize for common experiments has the internal diameter about the 40th or 50th of an inch, about 9 inches long, and made of thin glaſs, that the riſe and fall of the mercury may be better ſeen.

It is commonly obſerved of thermometers, that upon equal augmentations and diminutions of heat they ſeldom vary equally, though they are filled with the ſame liquor. To account for this circumſtance it ſhould be recollected that the variation of a thermometer is directly as the capacity of the ball, and inverſely as the baſe of the ſtem. Thus, if there be two mercurial thermometers, for example, and we call the capacites of the balls C and *c*, and the baſes of the ſtems B and *b*, the variations will be as C to *c* directly, and as B to *b* inverſely, or as $\frac{C}{B}$ to $\frac{c}{b}$. Conſequently the variations will not be equal in thoſe thermometers unleſs $\frac{C}{B}=\frac{c}{b}$: and this cannot be the caſe unleſs C : *c* : : B : *b*; therefore, to render the variations in the two thermometers equal, the capacities of their balls muſt be to each other as the baſes of their cylindrical ſtems.

The next thing to be conſidered, is of what number of degrees or diviſions the ſcale ought to conſiſt, and from what point it ought to commence. As the number of the diviſions of the ſcale is an arbitrary matter, the ſcales which have been employed differ much from one another in this circumſtance. Fahrenheit has made 180 degrees between the freezing and boiling water point. Amontons made 73, and Sir Iſaac Newton only 34. There is, however, one general maxim, which ought to be obſerved: *That ſuch an arithmetical number ſhould be choſen as can eaſily be divided and ſubdivided, and that the number of diviſions ſhould be ſo great that there ſhall ſeldom be occaſion for fractions.* The number 80 choſen by Reaumur anſwers extremely well in this reſpect, becauſe it can be divided by ſeveral figures without leaving a remainder; but it is too ſmall a number: the conſequence of which is, that the degrees are placed at too great a diſtance from one another, and fractions muſt therefore be often employed. We think, therefore, that 160 would have been a more convenient number. Fahrenheit's number 180 is large enough; but when divided its quotient ſoon becomes an odd number.

As to the point at which the ſcale ought to commence, various opinions have been entertained. If we knew the beginning or loweſt degree of heat, all philoſophers would agree that the loweſt point of the thermometer ought to be fixed there; but we know neither the loweſt nor the higheſt degrees of heat; we obſerve only the intermediate parts. All that we can do, then, is to begin it at ſome invariable point, to which thermometers made in different places may eaſily be adjuſted. If poſſible, too, it ought to be a point at which a natural well-known body receives ſome remarkable change from the effects of heat or cold. Fahrenheit began his ſcale at the point at which ſnow and ſalt congeal. Kirwan propoſes the freezing point of mercury. Sir Iſaac Newton, Hales, and Reaumur, adopted the freezing point of water. The objection to Fahrenheit's loweſt point is, that it commences at an artificial cold never known in nature, and to which we cannot refer our feelings, for it is what few can ever experience. There would be ſeveral great advantages gained, we allow, by adopting the freezing point of mercury. It is the loweſt degree of cold to which mercury can be applied as a meaſure; and it would render unneceſſary the uſe of the ſigns plus and minus, and the extenſion of the ſcale below 0. But we object to it, that it is not a point well known; for few, comparatively ſpeaking, who uſe thermometers, can have an opportunity of ſeeing mercury congealed. As to the other advantage to be gained by adopting the freezing point of mercury, namely, the abolition of negative numbers, we do not think it would counterbalance the advantage to be enjoyed by uſing a well-known point. Beſides, it may be aſked, Is there not a propriety in uſing negative numbers to expreſs the degree of cold, which is a negative thing? Heat and cold we can only judge of by our feelings: the point then at which the ſcale ſhould commence, ought to be a point which can form to us a ſtandard of heat and cold; a point familiar to us from being one of the moſt remarkable that occurs in nature, and therefore a point to which we can with moſt clearneſs and preciſion refer in our minds on all occaſions. This is the freezing point of water choſen by Sir Iſaac Newton, which of all the general changes produced in nature by cold is the moſt remarkable. It is therefore the moſt convenient point for the thermometers to be uſed in the temperate and frigid zones, or we may ſay over the globe, for even in the hotteſt countries of the torrid zone many of the mountains are perpetually covered with ſnow.

Having now explained the principles of the thermometer as fully as appears neceſſary in order to make it properly underſtood, we will here ſubjoin an account of thoſe thermometers which are at preſent in moſt general uſe. Theſe are Fahrenheit's, De l'Iſle's, Reaumur's, and Celſius's. Fahrenheit's is uſed in Britain, De l'Iſle's in Ruſſia, Reaumur's in France, and Celſius's in Sweden. They are all mercurial thermometers.

Fahrenheit's thermometer conſiſts of a ſlender cylindrical tube and a ſmall longitudinal bulb. To the ſide of the tube is annexed a ſcale which Fahrenheit divided into 600 parts, beginning with that of the ſevere cold which he had obſerved in Iceland in 1709, or that produced by ſurrounding the bulb of the thermometer with a mixture of ſnow or beaten ice and ſal ammoniac or ſea ſalt. This he apprehended to be the greateſt degree of cold, and accordingly he marked it, as the beginning of his ſcale, with 0; the point at which mercury begins to boil, he conceived to ſhew the greateſt degree of heat, and this he made the limit of his ſcale. The diſtance between theſe two points he divided into 600 equal parts or degrees; and by trials, he found that the mercury ſtood at 32 of theſe diviſions, when water juſt begins to freeze, or ſnow or ice juſt begins to thaw; it was therefore called the degree of the freezing point. When the tube was immerſed in boiling water, the mercury roſe to 212, which therefore is the boiling point, and is juſt 180 degrees above the former or freezing point. But the preſent method of making the ſcale of theſe thermometers, which is the ſort in moſt common uſe, is firſt to immerge the bulb of the thermometer in ice or ſnow juſt beginning to thaw, and mark the place where the mercury ſtands with a 32; then immerge it in boiling water, and again mark the place where the mercury ſtands in the tube, with the num. 212, exceeding the former by 180; dividing therefore the intermediate ſpace into 180 equal parts, will give the ſcale of the thermometer; which may afterwards be continued upwards and downwards at pleaſure.

Other thermometers of a ſimilar conſtruction have been accommodated to common uſe, having but a portion of the above ſcale. They have been made of a ſmall ſize and portable form, and adapted with appendages to particular purpoſes; and the tube with its annexed ſcale has often been encloſed in another thicker glaſs tube, alſo hermetically ſealed, to preſerve the thermometer from injury. And all theſe are called *Fahrenheit's thermometers.*

In 1733, M. De l'Iſle of Peterſburgh conſtructed a mercurial thermometer on the principles of Reaumur's ſpirit thermometer. In his thermometer, the whole bulk of quickſilver, when immerged in boiling water, is conceived to be divided into 100,000 parts; and from this one fixed point the various degrees of heat, either above or below it, are marked in theſe parts on the tube or ſcale, by the various expanſion or contraction of the quickſilver, in all imaginable varieties of heat.—Dr. Martine apprehends it would have been better if De l'Iſle had made the integer 100,000 parts, or fixed point, at freezing water, and from thence computed the dilatations or condenſations of the quickſilver in thoſe parts; as all the common obſervations of the weather, &c. would have been expreſſed by numbers increaſing as the heat increaſed, inſtead of decreaſing, or counting the contrary way. However, in practice it will not be very eaſy to determine exactly all the diviſions from the alteration of the bulk of the contained fluid. And beſides, as glaſs itſelf is dilated by heat, though in a leſs proportion than quickſilver, it is only the exceſs of the dilatation of the contained fluid above that of the glaſs that is obſerved; and therefore if different kinds of glaſs be differently affected by a given degree of heat, this will make a ſeeming difference in the dilatations of the quickſilver in the thermometers conſtructed in the Newtonian method, either by Reaumur's rule or De l'Iſle's. Accordingly it has been found, that the quickſilver in De l'Iſle's thermometers has ſtood at different degrees of the ſcale when immerged in thawing ſnow: having ſtood in ſome at 154°, while in others it has been at 156°, or even 158°.

The thermometer at preſent uſed in France is called *Reaumur's*; but it is very different from the one originally invented by Reaumur in 1730, and deſcribed in the Memoirs of the Academy of Sciences. The one invented by Reaumur was filled with ſpirit of wine; and though its ſcale was divided by the author into 80 parts, of which 0 was the freezing point, and 80 the boiling water-point, yet in fact 80 was only the boiling point of the ſpirit of wine that he employed, which, as Dr. Martine computes, correſponded with 180 of Fahrenheit. But the thermometer now in uſe in France is filled with mercury; and the boiling water point, which is at 80, correſponds with the 212th degree of Fahrenheit. The ſcale indeed commences at the freezing point, as the old one did. The new thermometer ought more properly to be called *De Luc's thermometer*, for it was firſt made by De Luc; and is in fact as different from Reaumur's as it is from Sir Iſaac Newton's. When De Luc had fixed the ſcale, and finiſhed an account of it, he ſhewed the manuſcript to M. De la Condamine. Condamine adviſed him to change the number 80; remarking, that ſuch was the inattention of philoſophers, that they would probably confound it with Reaumur's. De Luc's modeſty, as well as a predilection for the number 80, founded, as he thought, on philoſophical reaſons, made him decline following this advice. But he found by experience that the prediction of Condamine was too well founded.

The thermometer of Celſius, which is uſed in Sweden, has a ſcale of 100 degrees from the freezing to the boiling water point.

Theſe are the principal thermometers now uſed in Europe; and the temperatures indicated by any of them may be reduced into the correſponding degrees on any of the others by means of the following ſimple theorems; in which R ſignifies the degrees on the ſcale of Reaumur, F thoſe of Fahrenheit, and S thoſe of the Swediſh thermometer.

1. To convert the degrees of Reaumur into thoſe of Fahrenheit; $\frac{R\times 9}{4}+32=F$.

2. To convert the degrees of Fahrenheit into thoſe of Reaumur; $\frac{(F-32)\times 4}{9}=R$.

3. To convert the Swediſh degrees into thoſe of Fahrenheit; $\frac{S\times 9}{5}+32=F$.

4. To convert Fahrenheit's into Swediſh; $\frac{(F-32)\times 5}{9}=S$.

5. To convert Swediſh degrees into thoſe of Reaumur; $\frac{S\times 4}{5}=R$.

6. To convert Reaumur's degrees into Swediſh; $\frac{R\times 5}{4}=S$.

To ſuch readers as are unacquainted with the algebraic expreſſion of arithmetical formulæ, it will be ſufficient to expreſs one or two of theſe in words to explain their uſe.—1. Multiply the degree of Reaumur by 9, divide the product by 4, and to the quotient add 32, the ſum expreſſes the degree on the ſcale of Fahrenheit.—2. From the degree of Fahrenheit ſubtract 32, multiply the remainder by 4, and divide the product by 9, the quotient is the degree according to the ſcale of Reaumur, &c.

As in meteorological obſervations it is neceſſary to attend to the greateſt riſe and fall of the thermometer, attempts have been made to conſtruct a thermometer which might regiſter the greateſt degree of heat, or greateſt degree of cold, which took place during the abſence of the obſerver.

In 1782 Mr. Six propoſed a ſelf-regiſtering thermometer. It is properly a ſpirit-of-wine thermometer, though mercury is alſo employed for ſupporting an index. *ab* (fig. 10. pl. XXXVII.) is a thin tube of glaſs 16 inches long, and 5-16ths of an inch caliber: *cde* and *fgh* are ſmaller tubes, about 1-20th of an inch caliber. Theſe three tubes are filled with highly rectified ſpirit of wine, except the ſpace between *d* and *g*, which is filled with mercury. As the ſpirit of wine contracts or expands in the middle tube, the mercury falls or riſes in the outſide tubes. An index, made of thin wire with a knob, is placed on the ſurface, within each of theſe tubes, ſo light as to float upon it. *k* is a ſmall glaſs tube 3-4ths of an inch long, hermetically ſealed at each end, and incloſing a piece of ſteel wire nearly of its own length. At each end *l*, *m*, of this ſmall tube, a ſhort tube of black glaſs is fixed, of ſuch a diameter as to paſs freely up and down within either of the outſide tubes of the thermometer *ce* or *fh*. From the upper end of the index is drawn a ſpring of glaſs to the fineneſs of a hair, and about 5-7ths of an inch long; which being placed a little oblique, preſſes lightly againſt the inner ſurface of the tube, and prevents the index from deſcending when the mercury deſcends. Theſe indexes being inſerted one into each of the outſide tubes, it is eaſy to underſtand how they point out the greateſt heat or cold that has happened in the obſerver's abſence. When the ſpirit of wine in the middle tube expands, it preſſes down the mercury in the tube *hf*, and conſequently raiſes it in the tube *ec*; conſequently the index on the left hand tube is left behind and marks the greateſt cold, and the index in the right hand tube riſes and marks the greateſt heat.

In 1790 a paper was preſented to the Royal Society of Edinburgh, deſcribing two thermometers, newly invented, by Dr. John Rutherford of Middle Baliliſh; the one for regiſtering the higheſt and the other for regiſtering the loweſt degree of heat to which the thermometer has riſen or fallen during the abſence of the obſerver. An account of them may be found in the third volume of the Tranſactions of the Society.

A new ſelf-regiſtering thermometer has more lately been invented by Mr. Keith of Ravelſtone, which we conſider as the moſt ingenious, ſimple, and perfect, of any which has hitherto appeared. Its ſimplicity is ſo great, that it requires only a very ſhort deſcription to make it intelligible. It is conſtituted, firſt, of a thin glaſs tube about fourteen inches long, and 3-4ths of an inch caliber, cloſe or hermetically ſealed at top. To the lower end, which is open, there is joined a crooked glaſs tube ſeven inches long, and 4-10ths of an inch caliber, and open at its top, which, of courſe, is level with the middle of the firſt tube. The former tube is filled with the ſtrongeſt ſpirit of wine, and the latter tube with mercury. This is properly a ſpirit-of-wine thermometer, and the mercury is uſed merely to ſupport a piece of ivory or glaſs, to which is affixed a wire for raiſing one index or depreſſing another, according as the mercury riſes or falls. There is a ſmall conical piece of ivory or glaſs, of ſuch a weight as to float on the ſurface of the mercury. To the float is joined a wire called the *float-wire*, which reaches upwards, where it terminates in a knee bent at right angles. The float-wire, by means of an eye at its extremity, moves eaſily along a ſmall vertical harpſichord wire. There are two indexes made of thin black-oiled ſilk, which ſlide upwards or downwards with a force not more than two grains. The one placed above the knee points out the greateſt riſe, and the one placed below it points out the greateſt fall, of the thermometer.

When the inſtrument is to be prepared for an obſervation, both indexes are to be brought cloſe to the knee. It is evident, that when the mercury riſes, the float and float-wire, which can be moved with the ſmalleſt force, will be puſhed upwards till the mercury becomes ſtationary. As the knee of the float-wire moves upwards it will carry along with it the upper index. When the mercury again ſubſides, it leaves the index at the higheſt point to which it was raiſed, for it will not deſcend by its own weight: as the mercury falls, the float-wire does the ſame; it therefore brings along with it the lower index, and continues to depreſs it till it again becomes ſtationary or aſcends in the tube; in which caſe it leaves the lower index behind it as it had formerly left the upper. The ſcale to which the indexes point is placed parallel to the ſlender harpſichord wire. That the ſcale and indexes may not be injured by the wind and rain, a cylindrical glaſs cover, cloſe at top, and made ſo as exactly to fit, is placed over it.

The ingenious inventor has another improvement, which, if upon trial it be found to anſwer, will make this thermometer as perfect as can be deſired, provided there do not ariſe ſome errors from the variable preſſure of the atmoſphere. He propoſes to adapt clock-work to this thermometer, in ſuch a way as to regiſter with the utmoſt preciſion the degrees of heat and cold for every month, day, and minute, in the year. An account of this latter improvement may be ſeen in Nicholſon's Journal, vol. iii. 4to ſeries, or Edin. Tranſac. vol. iv.

The common contrivance for a ſelf-regiſtering thermometer, now ſold in moſt of the London ſhops, conſiſts ſimply of two thermometers, one mercurial and the other of alcohol (fig. 4. pl. XXXI.) having their ſtems horizontal: the former has for its index a ſmall bit of magnetical ſteel wire, and the latter a minute thread of glaſs, having its two ends formed into ſmall knobs by fuſion in the flame of a candle.

The magnetical bit of wire lies in the vacant ſpace of the mercurial thermometer, and is puſhed forward by the mercury whenever the temperature riſes, and puſhes that fluid againſt it: but when the temperature falls and the fluid retires, this index is left behind, and conſequently ſhews the maximum. The other index, or bit of glaſs, lies in the tube of the ſpirit thermometer immerſed in the alcohol, and when the ſpirit retires by depreſſion of temperature, the index is carried along with it in apparent contact with its interior ſurface: but on increaſe of temperature the ſpirit goes forward and leaves the index, which therefore ſhews the minimum of temperature ſince it was ſet. As theſe indexes merely lie in the tubes, their reſiſtance to motion is altogether inconſiderable. The ſteel index is brought to the mercury by applying a magnet on the outſide of the tube, and the other is duly placed at the end of the column of alcohol by inclining the whole inſtrument.

Mr. Nicholſon explains the operation of this inſtrument thus: "When the ſurface of the column of ſpirit is viewed by a magnifier, it is ſeen to have the form of a concave hemiſphere, which ſhews that the liquid is attracted by the glaſs. The glaſs in that place is conſequently attracted in the oppoſite direction by a force equal to that which is ſo employed in maintaining that concave figure; and if it were at liberty to move, it would be drawn back till the flat ſurface was reſtored. Let us ſuppoſe a ſmall ſtick or piece of glaſs to be looſe within the tube, and to protrude into the vacant ſpace beyond the ſurface of the alcohol. The fluid will be attracted alſo by this glaſs, and form a concave between its ſurface and that of the bore of the tube. But the ſmall interior piece being quite at liberty to move, will be drawn towards the ſpirit ſo long as the attractive force poſſeſſes any activity; that is, ſo long as any additional fluid hangs round the glaſs; or, in other words, until the end of the ſtick of glaſs is even with the ſurface. Whence it is ſeen that the ſmall piece of glaſs will be reſiſted, in any action that may tend to protrude it beyond the ſurface of the fluid; and if this reſiſtance be greater than the force required to ſlide it along in the tube (as in fact it is), the piece muſt be ſlided along as the alcohol contracts; ſo as always to keep the piece within the fluid. And this fact is accordingly obſerved to take place." Nich. Jour. N. S. N°. 47.

Mr. Leſlie, well known for his ingenious "Experimental Enquiry into the Nature and Propagation of Heat," has invented a *Differential Thermometer* for the meaſurement of minute variations of temperature. It conſiſts of two tubes, each terminating in a ſmall bulb of the ſame dimenſions, joined by the blow-pipe, and bent in the form of a U, a ſmall portion of dark coloured liquor having previouſly been introduced into one of the balls. After many trials, the fluid beſt adapted to the purpoſe was found to be a ſolution of carmine in concentrated ſulphuric acid. By managing the included air with the heat of the hand, this red liquor is made to ſtand at the required point of the oppoſite tube. This is the zero of a ſcale faſtened to that tube, and divided into equal parts above and below that point. The inſtrument is then fixed on a ſtand. It is manifeſt that when the liquor is at reſt, or points at zero, the column is preſſed in oppoſite directions by two portions of air equal in elaſticity, and containing equal quantities of caloric. Whatever heat, then, may be applied to the whole inſtrument, provided both bulbs receive it in the ſame degree, the liquor muſt remain at reſt. But if the one ball receives the ſlighteſt exceſs of temperature, the air which it contains will be proportionally expanded, and will puſh the liquid againſt the air in the other bulb with a force, varying as the difference between the temperatures of thoſe two portions of air: thus the equilibrium will be deſtroyed, and the fluid will riſe in the oppoſite tube. The degrees of the ſcale through which it paſſes will mark the ſucceſſive augmentations in the temperature of the ball, which is expoſed to the greateſt heat. So that this inſtrument is a balance of extreme delicacy for comparing the temperatures of its two ſcales.

It is a ſmall variation from this thermometer that conſtitutes

Mr. Leſlie's *Photometer*. Thoſe who wiſh to learn more of the nature of this latter-mentioned inſtrument, may conſult Mr. Leſlie's Treatiſe on Heat, Nicholſon's Journal, vol. iii. 4to. or ſome acute remarks in the Edinburgh Review, No. 13.

When thermometers are deviſed to meaſure very great degrees of heat, they are uſually called by another name. See PYROMETER.

The thermometer and barometer together are very uſeful in determining the altitudes of mountains, &c. according to the rules delivered in our firſt volume, book v. For this purpoſe they are fixed in ſuch a frame as to be conveniently portable. (See BAROMETER.) Other portable inſtruments by Mr. M'Guire and M. Humbolt, which we omitted mentioning in that article, are deſcribed, the former in the Tranſactions of the Royal Iriſh Academy for 1787, the latter in Journal de Phyſique, an 7. or Tilloch's Philoſophical Magazine, No. 15.

THRASHING MACHINES, in a country like ours, where agriculture has been ſo ſucceſsfully cultivated, can hardly be denied to be of great utility: for which reaſon, although theſe machines are not yet brought to ſuch a ſtate of perfection as is to be wiſhed, we conceive it will not be improper to give an account of ſome of the moſt ingenious.

The firſt thraſhing machine which has come to our knowledge is that manufactured in 1732 by Mr. *Michael Menzies* of Edinburgh: it conſiſted, as far as we have been able to aſcertain, of numerous inſtruments, reſembling flails, which were attached to a moveable beam, and inclined to the latter in an angle of ten degrees. On each ſide of ſuch beam were placed floors, or benches, on which the ſheaves were ſpread; the flails being moved forward and backward on theſe benches by a crank that was fixed to the end of an axle, revolving about thirty times in a minute.

The ſecond machine was inventedin 1753 by Mr. *Michael Sterling* of Dumblaine, Perthſhire: his firſt models were very imperfect; but, after repeated alterations, he completed it in its preſent form, in 1758; and it now conſiſts of an outer, or water-wheel, having an inner wheel, furniſhed with forty-eight cogs, and turning on the ſame axle. With this cog-wheel is connected a vertical trundle, or pinion, with ſeven notches; and the axle of which paſſes through a floor above the wheel; its upper pivot being ſecured in a beam ſix inches above the floor. At the height of three feet three inches from the latter, two ſtraight pieces of ſquared wood (each being four feet in length) are inſerted through the axle of the pinion, at right angles, ſo as to form four arms that are moved round horizontally. To the end of theſe arms are affixed four iron plates, each twenty inches in length, and eight inches in breadth at the extremity neareſt to the arms, but tapering to a point at the oppoſite ends.

The horizontal fly, here deſcribed, conſtitutes four thraſhers, and is incloſed in a cylindrical wooden box, that is three and a half feet high, and eight feet in diameter: on the top of this box is an opening eight inches in width, extending a foot and a half from the circumference to its centre, and through which the ſheaves of corn deſcend; the latter being previouſly opened, and laid ſeparately on a board provided with two ledges, gradually declining towards ſuch port, or opening. Within the cylindrical box there is an inclined plane, along which the ſtraw and grain fall into a wire-riddle two feet ſquare, that is placed immediately beneath a hole of a ſimilar ſize:—the riddle is jerked at each revolution of the ſpindle, by means of a knob fixed on its ſide; and is thruſt backward by a ſmall ſpring that preſſes it in a contrary direction. Thus, the ſhort ſtraw, together with the grain and chaff, that paſs through the wide riddle, fall inſtantly into an oblong ſtraight riddle, one end of which is raiſed, and the other depreſſed, by a ſimilar contrivance. And, as the riddle laſt-mentioned is not provided with a ledge at the lower end, the long chaff, which cannot paſs through, drops thence to the ground, while the grain and ſmaller chaff deſcend into a pair of common barn-fanners, and are thus ſeparated with great exactneſs. Theſe fanners are moved by means of a rope, that runs in a ſhallow groove cut on the circumference of the cog-wheel. In the mean time, the ſtraw collected in the lower part of the box over the wide riddle, and through an opening two feet and a half ſquare, is drawn down to the ground with a rake; by the perſons employed to form it into truſſes.

In 1772 another thraſhing-machine was invented by Mr. *Alderton* of Alnwick, and Mr. *Smart* of Wark, Northumberland. The operation was performed by rubbing: the ſheaves being carried round between an indented drum ſix feet in diameter, and numerous indented rollers, that were arranged round, and attached to, this drum by means of ſprings; ſo that during the revolution of the machinery, the corn was ſeparated from the ſtraw by conſtant friction againſt the flutings of the drum. But this contrivance was ſoon diſuſed; as many grains were thus cruſhed between the rollers.

The next invention is that of Mr. *Andrew Meikle*, in 1785, who obtained a patent, which is now expired: we have therefore given a plate (XXXIV), repreſenting in fig. 1. the plan of elevation; in fig. 2, the ground plan; and in fig. 3. the eſſential parts of the machinery, ſo as to convey a tolerably accurate idea of his principle.

A (fig. 1. and 2.) is a large horizontal ſpur-wheel, which has 276 cogs, and moves the pinion B, having fourteen teeth. The latter imparts motion to a crown-wheel, C, that is provided with eighty-four cogs, and moves a ſecond pinion, D, which is furniſhed with ſixteen teeth. This pinion D, turns the drum H I K L (fig. 1. 2. and 3.), being a hollow cylinder, three feet and a half in diameter, and placed horizontally: on its outſide are fixed, by means of ſcrew-bolts, four ſcutchers, or pieces of wood, one ſide of which is faced with a thin iron plate; and which are diſpoſed at an equal diſtance from each other, and at right angles to the axis of the drum.

P (fig. 2. and 3.) is an inclined board, on which the ſheaves are ſpread, and whence they are introduced between two fluted caſt-iron rollers, G, G (fig. 3.), that are three and a half inches in diameter, and revolve about thirty-five times in one minute. Theſe rollers being only three-fourths of an inch from the ſcutchers or leaves of the drum H I K L (fig. 1. and 2.), ſerve to keep the ſheaves ſteady, while the ſcutchers *a*, *b*, *c*, *d* (fig. 2. and 3.), move with conſiderable velocity, and thus ſeparate the grain from the ſtraw, while both are thrown on the concave rack M (fig. 2.), which lies horizontally with ſlender parallel ribs; ſo that the corn may paſs through them into the ſubjacent hopper N (fig. 1. and 3.).

O (fig. 3.) is a riddle or harp, through which the corn drops into a pair of fanners, P (fig. 1. and 3.), and from theſe it is generally obtained in a ſtate fit for the market.

Q R T S is a rake, conſiſting of four leaves, or thin pieces of wood; at the extremity of each is placed a row of teeth, *e*, *f*, *g*, *h*, that are five inches long. This rake moves in the concave rack M, (fig. 2.), in a circular direction; while the teeth catch the ſtraw that had been thrown by the ſcutchers *a*, *b*, *c*, *d*, into the rack, and remove it to the contiguous place, V.

W (fig. 1.) repreſents the horſe's courſe, which is twenty-ſeven feet in diameter.

X (fig. 1. and 2.) is the pillar for ſupporting the beams on which the axle of the ſpur-wheel is fixed.

Y, Y, Y (fig. 1.), and Y, Y (fig. 2.), ſhew the ſpindles, the deſign of which is to move the two fluted rollers, the rake, and the fanners.

To the deſcription now given we have only to add, that the drum has a covering of wood at a ſmall diſtance above it, for the purpoſe of keeping the ſheaves cloſe to the ſcutchers.

The number of perſons requiſite for attending the mill when working is ſix: one perſon drives the horſes; a ſecond hands the ſheaves to a third who unites them, while a fourth ſpreads them on the inclined boards, and preſſes them gently between the rollers; a fifth perſon is neceſſary to riddle the corn as it falls from the fanners, and a ſixth to remove the ſtraw.

This machine can be moved equally well by water, wind, or horſes. Mr. Meikle has made ſuch improvements on the wind-mill as to render it much more manageable and convenient than formerly; and we are informed many wind-mills are now erecting in different parts of the country. As to the comparative expence of theſe different machines, the erection of the horſe-machine is leaſt; but then the expence of employing horſes muſt be taken into conſideration. One of this kind may be erected for 70*l.* A water-mill will coſt 10*l.* more, on account of the expence of the water-wheel. A wind-mill will coſt from 200*l.* to 300*l.* ſterling.

In thraſhing machines, however, cheapneſs ſhould not be the only conſideration. It often happens in machinery, that things apparently cheap are ultimately very dear. Thraſhing of corn requires a ſtrong power, which neither weak men nor ſlight machines are competent to. On this account, ſtrong and durable machines are to be recommended as cheapeſt in the end; performing more work, in a better manner, and not needing frequent repairs.

Some other well-conſtructed thraſhing-machines are deſcribed in Gray's Experienced Mill-wright, and in the Repertory of Arts and Manufactures.

With reſpect to the quantity of corn which a machine will thraſh in a given time, it is not eaſy to give any preciſe information: the moſt important we have yet met with is given by Mr. Fenwick, who found from numerous experiments that a power capable of raiſing a weight of 1000 pounds with a uniform velocity of fifteen feet per minute, will thraſh two bolls (eight buſhels) of wheat in an hour; and that a power ſufficient to raiſe the ſame weight with a velocity of twenty-two feet per minute, will thraſh three bolls of the ſame grain in an hour. From theſe facts, this gentleman has computed the following table, which is applicable to machines that are driven either by water or horſes.

TABLE *of the power of thraſhing-machines.*

Gallons of water per minute, ale-meaſure, diſcharged on an overſhot wheel 10 feet in diameter.	Gallons of water per minute, ale-meaſure, diſcharged on an overſhot wheel 12 feet in diameter.	Gallons of water per minute, ale-meaſure, diſcharged on an overſhot wheel 20 feet in diameter.	Number of horſes working 9½ hours.	Bolls of wheat thraſhed in an hour.	Bolls thraſhed in 9½ hours actual working, or in a day.
230	160	130	1	2	19
390	296	205	2	3	28½
528	380	272	3	5	47½
660	470	340	4	7	66½
790	565	400	5	9	85½
970	680	500	6	10	95
1	2	3	4	5	6

The firſt four columns of the preceding table contain different quantities of impelling power, and the laſt two exhibit the number of bolls of wheat in Wincheſter meaſure, which ſuch powers are capable of thraſhing in an hour, or in a day. Six horſes, for example, are capable of thraſhing ten bolls of wheat in an hour, or ninety-five in the ſpace of nine hours and a half, or a working day; and 680 gallons of water diſcharged into the buckets of an overſhot water-wheel during a minute, will thraſh the ſame quantity of grain.

TIDE-MILLS, as their name imports, are ſuch as employ for their firſt mover the flowing and ebbing tide, either in the ſea or a river.

Mills of this kind have not often, we believe, been erected in England, though ſeveral of our rivers, and particularly the Thames, the Humber, and the Severn, in which the tide riſes to a great height, furniſh a very powerful mover to drive any kind of machinery, and would allow of tide-mills being very advantageouſly conſtructed upon their banks. The erection of ſuch mills is not to be recommended univerſally, as they are attended with a conſiderable original expence; beſides that ſome of their parts will require frequent repairs: but in ſome places where coals are very dear they may, on the whole, be found leſs expenſive than ſteam-engines to perform the ſame work, and may on *that* account be preferred even to them.

We have not been able to aſcertain who was the firſt contriver of a tide-mill in this country, nor at what time one was firſt erected. The French have not been ſo negligent reſpecting the origin of this important invention as to let it drop into obſcurity; but have taken care to inform us that ſuch mills were uſed in France early in the laſt century. Belidor mentions the name of the inventor, at the ſame time that he ſtates ſome peculiar advantages of this ſpecies of machine. "L'on en attribue," ſays he, "la première invention à un nomme *Perſe*, maître charpentier de Dunkerque, qui mérite aſſurément beaucoup d'éloge, n'y ayant point de gloire plus digne d'un bon citoyen, que celle de produire, quelqu' invention utile à la ſociete. En effet, combien n'y a-t'il point de choſes eſſentielles à la vie, dont on ne connoît le prix que quand on en eſt privé: les moulins en général ſont dans ce cas-là. On doit ſçavoir bon gré à ceux qui nous ont mis en état d'en conſtruire par-tout: par exemple à Calais, comme il n'y ſerpente point de rivieres, on n'y a point fait juſqu'ici de moulins à eau, & ceux qui vont par le vent chômant un partie de l'année, il y a des tems où cette ville ſe trouve ſans farine, & j'ai vu la garniſon en 1730, obligée de faire venir du pain de Saint-Omer, au lieu qu'en ſe ſervant du flux & reflux de la mer, on pourroit conſtruire autant de moulins à eau que l'on voudroit: il y a d'autres villes dans le voiſinage de la mer ſujettes au même inconvénient, parce qu' apparemment elles ignorent le moyen d'y remédier."

Mills to be worked by the riſing and falling of the tide admit of great variety in the eſſential parts of their conſtruction; but this variety may perhaps be reduced to four general heads, according to the manner of action of the water-wheel. 1. The water-wheel may turn one way when the tide riſes, and the contrary when it falls. 2. The water-wheel may be made to turn always in one direction. 3. The water-wheel may fall and riſe as the tide ebbs and flows. 4. The axle of the water-wheel may be ſo fixed as that it ſhall neither riſe nor fall, though the rotatory motion ſhall be given to the wheel, while at one time it is only partly, at another completely, immerſed in the fluid. In the mills we have examined, the firſt and third of theſe diviſions have been uſually exemplified in one machine; and the ſecond and fourth may readily be united in another: we ſhall, therefore, ſpeak of them under two diviſions only.

I. *When the water-wheel riſes and falls, and turns one way with the riſing tide, and the contrary when it ebbs.* In order to explain the nature of this ſpecies of tide-mill, we ſhall deſcribe one which has lately been erected on the right bank of the Thames at Eaſt-Greenwich, under the direction of Mr. John Lloyd, an ingenious engineer of Brewer's-green, Weſtminſter.

This mill is intended to grind *corn*, and works 8 pairs of ſtones. The ſide of the mill-houſe parallel to the courſe of the river meaſures 40 feet within; and as the whole of this may be opened to the river by ſluice-gates, which are carried down to the low water-mark in the river, there is a forty-feet waterway to the mill: through this waterway the water paſſes during the riſing tide into a large reſervoir, which occupies about 4 acres of land: and beyond this reſervoir is a ſmaller one in which water is kept, for the purpoſe of being let out occaſionally at low water to cleanſe the whole works from mud and ſediment, which would otherwiſe in time clog the machinery. The water-wheel has its axle in a poſition parallel to the ſide of the river, that is, parallel to the ſluice-gates which admit water from the river: the length of this wheel is 26 feet, its diameter 11 feet, and its number of float-boards 32. Theſe boards do not each run on in one plane from one end of the wheel to the other, but the whole length of the wheel is divided into four equal portions, and the parts of the float-boards belonging to each of theſe portions fall gradually one lower than another, each by one fourth of the diſtance from one board to another, meaſuring on the circumference of the wheel. This contrivance, which will be better underſtood by referring to fig. 6. pl. XXXV. (ſhewing a part of the wheel), is intended to equalize the action of the water upon the wheel, and prevent its moving by jerks. The wheel, with its incumbent apparatus, weighs about 20 tons, the whole of which is raiſed by the impulſe of the flowing tide when admitted through the ſluice-gates. It is placed in the middle of the water-way, leaving a paſſage on each ſide of about 6 feet for the water to flow into the reſervoir, beſides that which in its motion turns the wheel round. Soon after the tide has riſen to the higheſt (which at this mill is often 20 feet above the low water-mark), the water is permitted to run back again from the reſervoir into the river, and by this means it gives a rotatory motion to the water-wheel, in a contrary direction to that with which it moved when impelled by the riſing tide: the contrivance by which the wheel is raiſed and depreſſed, and that by which the whole interior motions of the mill are preſerved in the ſame direction, although that in which the water-wheel moves is changed, are ſo truly ingenious as to deſerve a diſtinct deſcription, illuſtrated by diagrams. Let, then, AB (fig. 5. pl. XXXV.) be a ſection of the water-wheel, 1, 2, 3, 4, 5, &c. its floats, CD the firſt cog-wheel upon the ſame axis as the water-wheel: the vertical ſhaft PE carries the two equal wallower-wheels E and F, which are ſo ſituated on the ſhaft that one or other of them may, as occaſion requires, be brought to be driven by the firſt wheel CD; and thus (by what has been ſaid under the article Reversing *of motion*) the firſt wheel acting upon F and E at points diametrically oppoſite, will, although its own motion is reverſed, communicate the rotatory motion to the vertical ſhaft always in [illegible] the ſame direction. In the figure the wheel E is ſhewn in gear, while F is clear of the cog-wheel CD; and at the turn of the tide the wheel F is let into gear, and E is thrown out: this is effected by the lever G, whoſe fulcrum is at H, the other end being ſuſpended by the rack K, which has hold of the pinion L on the ſame axle as the wheel M; into this wheel plays the pinion N, the winch O on the other end of whoſe axle furniſhes ſufficient advantage to enable a man to elevate or depreſs the wallower-wheels, as required. The centre of the lever may be ſhewn more clearly by fig. 6. pl. XXXV. where *a b* is a ſection of the lever, which is compoſed of two ſtrong bars of iron, as *a b*: there are two ſteel ſtuds or pins which work in the grooves of the grooved wheel I, this wheel being fixed on the four rods ſurrounding the ſhaft, of which three only can be ſhewn in the figures, as *c*, *d*, *e*; the ends of theſe are ſcrewed faſt by bolts to the ſockets of the wallower-wheels, and they are nicely fitted on the vertical ſhaft ſo as to ſlide with little friction: thus the wallowers may be raiſed or lowered upon the upright ſhaft, while the gudgeon on which it turns retains the ſame poſition. When the top wallower is in gear, it reſts on a ſhoulder that prevents it from going too far down; and when the bottom one is in gear there is a bolt that goes through the top wheel ſocket and ſhaft, which takes the weight from the lever G, at the ſame time that it prevents much friction on the ſtuds or pins of the lever which works in the grooved wheel I.

When the tide is flowing after the mill has ſtopped a ſufficient time to gain a moderate head of water, the fluid is ſuffered to enter and fall upon the wheel at the ſluice Q (fig. 5.), and the tail water to run out at the ſluice R. The hydroſtatic preſſure of the head of water acting againſt the bottom of the wheel-frame S, and at the ſame time acting between the folding-gates TW, which are thus converted into very large hydroſtatic bellows, buoys up the wheel and frame (though weighing, as before obſerved, nearly 20 tons), and makes them gradually to riſe higher and higher, ſo that the wheel is never, as the workmen expreſs it, *drowned* in the flowing water; nor can the water eſcape under the wheel-frame, being prevented by the folding-gates, which paſs from one end to the other of the wheel. In this way the wheel and frame are buoyed up by a head of 4 feet; and the mill works with a head of 5 or 5½ feet.

When the tide is ebbing, and the water from the reſervoir running back again into the river, it might perhaps be expected that in conſequence of the gradual ſubſiding of the water the water-wheel ſhould as gradually lower: but leſt any of the water confined between the wheel-frame at S and the folding-gates TW ſhould prevent this, there are ſtrong rackworks of caſt-iron, by which the wheel-frame can be either ſuſpended at any altitude or gradually let down ſo as to give the water returning from the reſervoir an advantageous head upon the wheel: then the ſluice R is ſhut, and V opened as well as X, the water entering at X to act upon the wheel, and flowing out at R. The upper ſurface of the wheel-frame is quadrangular, and at each angle is a ſtrong caſt-iron bar, which ſlides up and down in a proper groove, that admits of the vertical motion, but prevents all ſuch lateral deviation as might be occaſioned by the impulſion of the ſtream.

At each end of the water-wheel there is a vertical ſhaft, with wallowers and a firſt cog-wheel, as F, E, and CD; and each of theſe vertical ſhafts turns a large horizontal wheel at a ſuitable diſtance above the wallowers, while each horizontal wheel drives 4 equal pinions placed at equal or quadrantal diſtances on its periphery, each pinion having a vertical ſpindle, on the upper part of which the upper millſtone of its reſpective pair is fixed. Other wheels driven by one or other of theſe pinions giving motion to the bolting and dreſſing machines, and different ſubordinate parts of the mill.

Although the vertical ſhaft at each end of the water-wheel riſes and falls with that wheel, yet the large horizontal wheel turning with ſuch ſhaft does not likewiſe riſe and fall, but remains always in the ſame horizontal plane, and in contact with the four pinions it drives. The contrivance for this purpoſe is very ſimple, but very efficacious: each great horizontal wheel has a nave, which runs upon friction-rollers, and has a ſquare aperture paſſing through it vertically, juſt large enough to allow the ſhaft P to ſlide freely up and down in it, but not to turn round without communicating its rotatory motion to the wheel: thus the weight of the wheel cauſes it to preſs upon the friction-rollers, and retain the ſame horizontal planes, and the action of the angles of the vertical ſhaft upon the correſponding parts of the ſquare orifice in the nave cauſes it to partake of the rotatory motion, ſuch motion being always in one direction in conſequence of the contrivance by which one or other of the wallowers EF is brought into contact with the oppoſite points of the firſt cog-wheel CD.

Several of the ſubordinate parts of this mill are admirably conſtructed; but we can only notice here the means by which the direction of the motion in the dreſſing and bolting machines may be varied at pleaſure. On a vertical ſhaft are fixed, at the diſtance of about 15 or 18 inches, two equal cog-wheels, and another toothed wheel attached to a horizontal axle is made ſo as to be moveable up and down by a ſcrew, and thus brought into contact with either the upper or lower of the two cog-wheels on the vertical ſhaft; thus, it is manifeſt the motion is reverſed with great facility by changing the poſition of the horizontal axle ſo that the wheel upon it may be driven by the two cog-wheels alternately. A wheel and pinion working at the other end of the horizontal axle will communicate the motion to the dreſſing-machines.

Mr. W. Dryden, Mr. Lloyd's foreman, employed in the erection of this mill, ſuggeſts that a nearly ſimilar mode may be advantageouſly adopted in working the dreſſing-machines in wind-mills: three wheels, all of different diameters, may be employed, two of them, as A and C, turning upon a vertical ſhaft, and the third, B, upon an inclined one. In fig. 10. pl. XXXV. the wheels A and B are ſhewn in gear, while C is out: and if A be ſtruck out by ſome ſuch contrivance as is adopted with regard to the firſt cog-wheel and wallowers (fig. 5. 6.), C would come in contact with B, while A would be free, and ſo communicate a motion to B the reverſe way. By this contrivance it would be eaſy, when the winds are ſtrong and give a rapid motion to the vertical axle, to bring C to drive B the wheel on the axle of the dreſſing-machines; and on the contrary, when the wind was ſlack, and the conſequent motion of the machinery ſlow, let C be thrown out of gear and the wheel B driven by the larger wheel A, as ſhewn in the figure.

We ſhould have been glad to ſee adopted in this well-conſtructed mill a contrivance recommended and purſued by the American millwrights, for raiſing the ground corn to the cooling-boxes or beaches from which it is to be conveyed into the bolting-machine. In this mill, as in all we have ſeen, the corn is put into bags at the troughs below the mill-ſtones, and thence raiſed to the top of the mill-houſe by a rope folding upon barrels turned by ſome of the interior machinery of the mill. In the American method a large ſcrew is placed horizontally in the trough which receives the flour from the millſtones. The thread or ſpiral line of the ſcrew is compoſed of pieces of wood about two inches broad and three long, fixed into a wooden cylinder ſeven or eight feet in length, which forms the axis of the ſcrew. When the ſcrew is turned round this axis, it forces the meal from one end of the trough to the other, where it falls into another trough, from which it is raiſed to the top of the mill-houſe by means of elevators, a piece of machinery ſimilar to the chain-pump. Theſe elevators conſiſt of a chain of buckets or concave veſſels like large teacups, fixed at proper diſtances upon a leathern band, which goes round two wheels, one of which is placed at the top of the mill-houſe, and the other at the bottom, in the meal-trough. When the wheels are put in motion, the band revolves, and the buckets, dipping into the meal-trough, convey the flour to the upper ſtory, where they diſcharge their contents. The band of buckets is incloſed in two ſquare boxes, in order to keep them clean, and preſerve them from injury.

But it is time to direct our attention,

3. To *tide-mills in which the axle of the water-wheel neither riſes nor falls, and in which that wheel is made always to revolve in the ſame direction.*

A water-wheel of this kind muſt manifeſtly at the time of high-tide be almoſt if not entirely immerſed in the fluid: and to conſtruct a wheel to work under ſuch circumſtances is, obviouſly, a matter which requires no ſmall ſkill and ingenuity.

The firſt perſons who deviſed a wheel which might be turned by the tide, when completely immerſed in it, were Meſſrs. *Goſſet* and *de la Deuille*. Their wheel is deſcribed by Belidor in nearly the following terms: Suppoſe GH (fig. 12. pl. XXXV.) to denote the ſurface of the water at high-tide, the line LM the ſurface at low water, and that the current follows the direction of the arrow N; the problem is to conſtruct the wheel ſuch that it may always turn upon its axis IK. The figure juſt referred to is a profile of an aſſemblage of carpentry which muſt be repeated ſeveral times along the arbor, according to the length which it is propoſed to give to the float-boards; and the planks or plates which compoſe theſe floats muſt be hung to the other parts of the frame by as many joints as are neceſſary to enable them to ſuſtain the impulſe of the water without bending. The ſole peculiarity of this wheel conſiſts in hanging upon the tranſverſe beams in the frame-work, by hinges, the planks which are to compoſe the float-boards; ſo that they may preſent themſelves in face, as D,D,D, when they are at the bottom of the wheel, to receive the full ſtroke of the ſtream; and, on the contrary, they preſent only their edges, as at A, A, A, when they are brought towards the ſummit of the wheel: hence, the water having a far greater effect upon the lower than the upper parts of the wheel, compels it to revolve in the order of the letters; inſtead of which, if the floatboards were fixed, as in the uſual way, the impulſe of the fluid upon the wheel would be nearly the ſame in all its parts, and it would remain immoveable.

We ſee, at once, that the boards D, D, D, having moved towards M, then begin to float, as at E, E, E, and more ſtill at F, F, F, but that it is not till they arrive at A,A,A, that they attain the horizontal poſition; after that, having arrived at B, B, B, they begin to drop towards the beams to which they are hooked, and as ſoon as they have paſſed the level of the axle IK, the ſtream commences its full action upon them; which it attains completely between C, C, C, and E, E, E, and this whether the ſurface of the water be at GH or at LM; for even in the latter caſe it is manifeſt that the float-boards are entirely immerſed when in the vertical poſition PQ. Belidor ſays he was preſent at the firſt trial of ſuch a wheel at Paris, and that it was attended with all the ſucceſs that could be deſired.

A water-wheel has been lately invented by Mr. Dryden, which will work when nearly immerſed in the water of a flowing tide. Fig. 4. pl. XXXV. is an elevation of this wheel, its upper parts being ſuppoſed to ſtand a foot or two higher than the tide ever riſes: the axis of this wheel remains always in one place, and the wheel will work at high water when the head is at B and the tail-water at the dotted line A; it will alſo perform nearly the ſame work when the head is at C, and the tail-water level with the bottom of the wheel. The floats are all ſet at one and the ſame angle with the reſpective radii of the wheel, as may be ſeen in the figure, and are made ſo as to have an opening of at leaſt an inch between each float and the drum-boarding of the wheel. This opening is intended to prevent the wheel from being impeded by the tail-water; for as the bucket riſes out of the water there can be no vacuum formed in it, there being a full ſupply of air, in conſequence of which the water leaves the wheel deliberately. The caſe is different with regard to wheels made in the common way: for if ſuch are *open* wheels, the floats are made in ſuch a manner as to throw the tail-water if they are immerſed any depth in it; or, if they are *cloſe*, the wheel wants proper vent for the air to prevent the formation of a vacuum in the riſing bucket, or what is called by the miller "ſucking up the tail-water." At D is planking made circular to fit the wheel pretty cloſe for rather more than the ſpace of two floats, ſo as to confine the water nearly cloſe to the wheel. E, F, G, H, are fluices which are all connected together by the iron bar I, and lifted with the aſſiſtance of a wheel, two pinions, and a winch, the firſt pinion working into the rack K: theſe fluices are merely for ſtopping the wheel when occaſion requires, although one might be ſufficient to ſupply the wheel. The rings of this wheel may be made either of caſt-iron or of wood; the floats may be iron plates riveted together. The flanches on the arms of the wheel exhibited in the ſketch are intended to facilitate the fixing of the firſt cog-wheel: the ring of the wheel may be fixed to the flanches at the extremity of the arms, and the large flanch made faſt to the axle will receive the middle part of the wheel.

Fig. 4. pl. XXXVII. is a plan of the houſe in which either of the two latter wheels may be fixed, ſhowing in what manner the water may be conveyed always on one ſide of the wheel by the aſſiſtance of the four gates A, B, C, and D. When the mill is working from the river, A and B are open, the arrows point out the way the water runs from the river to the baſin; and the dotted lines on the contrary the courſe from the baſin to the river, when A, B, are ſhut, and C, D, opened. Theſe gates are made to turn on an axle, which is about ſix inches from the middle of the gate; and on the top of the axle is a half-wheel: by ſome crane-work connected to it, the gate can be opened or ſhut at pleaſure: when a head of water preſſes againſt the gates, they will open great part of the way of themſelves, by only letting the catches that keep them ſhut be lifted out of their place. X, Y, are two knees of caſt-iron, to ſupport the poſts that the gates are fixed to. The walls of the building are repreſented at *a*, *b*, *c*, and *d*.

The reader will now be able to form an eſtimate of the comparative value and ingenuity of the two kinds of tide-mills here deſcribed. The ſimplicity of conſtruction of the wheels of Goſſet, de la Deuille, and Dryden, recommend them ſtrongly; but we entertain ſome doubts of their being completely ſucceſsful in practice: had the curious wheel with the folding gates, &c. figs. 5. 6. pl. XXXV. been placed with its axle perpendicular inſtead of parallel to the courſe of the river, the water might then have always been admitted to act upon the ſame ſide of it, and the hydroſtatic preſſure would have operated as completely in lowering it continually during the time of ebb, as in raiſing it continually during the riſing of the tide: thus, as appears to us, would the labour of a man be ſaved, who according to the preſent conſtruction muſt attend the water-wheel; and all the additional apparatus now requiſite to ſhift the ſpur-wheels would at the ſame time be ſaved, and a conſequent diminution of original expence.

TURNING, the art of forming hard bodies, as wood, ivory, iron, into a round or oval ſhape by means of a machine called a *lathe*. This art was well known to the ancients, and ſeems to have been carried by them to a very great degree of perfection; at leaſt, if we believe the teſtimony of Pliny and ſeveral other authors, who tell us, that thoſe precious vaſes enriched with figures in half-relief, which ſtill adorn our cabinets, were turned on the lathe.

The art of turning is of conſiderable importance, as it contributes eſſentially to the perfection of ſeveral other arts. The architect uſes it for many ornaments both within and without highly finiſhed houſes. The mathematician, the aſtronomer, and the natural philoſopher, have recourſe to it, not only to embelliſh their inſtruments, but alſo to give them the neceſſary dimenſion and preciſion: and it is an art abſolutely neceſſary to the goldſmith, the watchmaker, the joiner, and the ſmith.

Turning is performed by the lathe, of which there are various kinds, and ſeveral inſtruments, as gouges, chiſels, drills, formers, ſcrew tales, uſed for cutting what is to be turned into its proper form as the lathe turns round. The moſt ſimple kind of lathe is a well-known inſtrument, and need not be deſcribed here: the improved lathes manufactured by Mr. *Henry Maudſlay*, of Margaret-ſtreet, Cavendiſh-ſquare, are the moſt curious as well as the moſt uſeful of any we have ſeen. Mr. *J. Farey*, jun. who took the drawings of theſe elegant ſpecimens of mechanical ingenuity, has accompanied them with a deſcription, nearly as below. A (pl. XXXVI. fig. 1.) is the great wheel, with four grooves on the rim: it is worked by a crank B and treadle C, in the common way; the catgut which goes round this wheel paſſes alſo round a ſmaller wheel D, called *the mandrel*, which has four grooves on its circumference of different diameters for giving it different velocities, correſponding with the four grooves on the great wheel A. In order to make the ſame band ſuit, when applied to all the different grooves on the mandrel D, the wheel A can be elevated or depreſſed by a ſcrew *a*, and another at the other end of the axle; and the connecting-rod C can be lengthened or ſhortened by ſcrewing the hooks at each end of it further out of, or into it. The end M, fig. 2., of the ſpindle of the mandrel D, is pointed, and works in a hole in the end of a ſcrew, put through the ſtandard E, fig. 1.; the other end of the bearing F, fig. 2. is conical, and works in a conical ſocket in the ſtandard F, fig. 1. ſo that by tightening up the ſcrew in E, the conical end F may at any time be made to fit its ſocket: the puppet G has a cylindric hole through its top to receive the poliſhed pointed rod *d*, which is moved by the ſcrew *e*, and fixed by the ſcrew *f*; the whole puppet is fixed on the triangular priſmatic bar H, by a clamp fig. 8., the two ends of which, *a*, *b*, are put through holes, *b*, in the bottom of the puppet under the bar, and the whole is fixed by the ſcrew *c* preſſing againſt it: by this means, the puppet can be taken off the bar without firſt taking off the ſtandard I, as in the common lathes: and the triangular bar is found to be far preferable to the double rectangular one in common uſe. The reſt J is a ſimilar contrivance; it is in three pieces; ſee figs. 3, 4, and 5. Fig. 4. is a piece, the opening (*a*, *b*, *c*) in which is laid upon the bar H, fig. 1.; the four legs *d d d d* of fig. 5. are then put up under the bar (into the receſſes in fig. 4. which are made to receive them) ſo that the notches in *d d d d* may be level with the top of fig. 4., the two beads *e f* in fig. 3. are then ſlid into the notches in the top of *d d d d*, fig. 4. to keep the whole together; the groove *i*. is to receive a correſponding piece on *e f*, fig. 3., to ſteady it; the whole of fig. 3. has a metallic cover, to keep the chips out of the grooves. It is plain, that by tightening the ſcrew *h* in the bottom of fig. 4. the whole will be fixed and prevented from ſliding along the bar H, and fig. 3. from ſliding in a direction perpendicular to the bar; the piece *l*, fig. 3., on which the tool is laid, can be raiſed or lowered at pleaſure, and fixed by the ſcrew *m*. On the end *n* of the ſpindle P, figs. 1. and 2., is ſcrewed occaſionally an *univerſal* CHUCK for holding any kind of work which is to be turned (ſee fig. 6.). A is the female ſcrew to receive the ſcrew *n*, fig. 1.; near the bottom of the ſcrew A is another ſcrew BB, which is prevented from moving endways by a collar in the middle of it fixed to the ſcrew A: one end of the ſcrew BB is cut *right handed*, and the other *left handed*; ſo that by turning the ſcrew one way, the two nuts EF will recede from each other, or by turning it the contrary way, they will advance towards each other: the two nuts EF paſs through an opening in the plate C, and project beyond the ſame, carrying jaws like thoſe of a vice, by which the ſubject to be turned is held.

For turning faces of wheels, hollow work, &c. where great accuracy is wanted, Mr. *Maudſlay* has contrived a curious apparatus which he calls a *ſlide-tool*, repreſented by fig. 7., where EEE is the opening to receive the bar H, fig. 1., and it is fixed by the clamp, fig. 8. as before deſcribed: the tool for cutting, &c. is fixed in the two holders *b b* by their ſcrews; theſe holders are faſtened to a ſliding plate *a*, which can be moved backwards and forwards by the ſcrew *c*, cauſing the tool to advance or recede; fig. 9. repreſents the under ſide (turned upward) of the part AA, in which the ſcrew *c* is ſeen fixed at each end, and the nut *d*, which is attached to the underſide of the plate *a*, working upon it. When it is neceſſary, as in the turning of the inſide of cones, &c. that the tool ſhould not be parallel to the ſpindle P, the ſcrew *e* and another ſimilar one behind muſt be looſened, the tool ſet at the proper angle, and then be ſcrewed tight again. In order to make the piece AA move truly when it is turned round, there is a hole *f*, fig. 9., to receive a knob *g*, fig. 14., upon the plate B, which acts as a centre, and keeps it in its place: there are three holes on each ſide in the plate B, fig. 12., to put the ſcrew *e* in at different times, thus giving to the tool a greater range than the circular openings SS will admit. The part EEEE, repreſented ſeparately, and inverted in fig. 10, is of caſt-iron, and has a ſcrew *h* working in it ſimilar to fig. 9.; the nut of this ſcrew is attached to the bottom of the ſlide H, fig. 11., at *t*, which ſlides in the groove *i*, figs. 7. and 10.; at one end of it is a box containing a ſcrew *m*, to be hereafter deſcribed, and at the other is a frame of braſs KK. Near the ſame end of the ſlide is a pin L, projecting above the plate, which is put through an opening, J in fig. 12., to ſteady it, while the other end, C of fig. 12., is put through an opening M in the box D, fig. 11. In the part C is an oblique ſlit *ll* to receive a ſtub which projects from the bottom of the nut *n*, worked by the ſcrew *m*, fig. 11.: by this arrangement it is obvious that if the ſcrew *m* is worked, the ſtub of the nut *n*, acting againſt the ſide of the ſlit *ll* as an inclined plane, will move it either backwards or forwards through the opening M; a metal cover *r*, fig. 14., is occaſionally put over the opening for the nut *n* and ſcrew *m*, to prevent the chips from falling in. Near the four corners of the frame, fig. 12., are four ſmall projections *oooo*, with inclined ſides, which fit into the four openings *pppp* of figs. 13. and 7.; theſe openings are cut out in two braſs plates, which are ſcrewed on at right angles to the plate BB, figs. 7. and 13.; the ends *qqqq* of theſe plates ſlide between the edges of the frame KK and the box D, ſo as to prevent any other motion than a vertical one.—When this *ſlide-tool* is uſed, the puppet G is to be removed or puſhed back further from F, and the tool is put upon the bar H, figs. 1., and fixed in the place of the reſt J by the clamp, fig. 8.; the diſtance from the centre *n* is adjuſted by the ſcrew *h*, which moves the ſlide, fig. 11. in the grooves *i*, fig. 7. and 10. with the whole apparatus upon it: by the ſcrew *m*, figs. 7. and 11., as before deſcribed, the ſlide, fig. 12., may be moved in a direction perpendicular to the bar H, fig. 1.; and its projections *oo* acting againſt the ſlits *pp*, figs. 7. and 13., as inclined planes, will raiſe or lower the plate B as is required.

The tool, which has been before fixed in the holders *bb*, can be ſet at the proper angle, by looſening the ſcrew *c*, as previouſly deſcribed: and, laſtly, the tool with the holders and ſlider *a* can be advanced or withdrawn by working the ſcrew *e*. The nuts of the ſcrews *c* and *h*, fig. 7., are not ſcrewed faſt to the ſliding plates, but are held by two pins *t*, fig. 11., which fit into grooves *u*, fig. 10., in each ſide of the nut: by theſe means, the ſliding plate can at any time be taken out by only unſcrewing one of the braſs ſides from the groove *i*, without taking out the ſcrew and nut. In order to make the grooves always fit their ſlides, the two pieces of braſs *yy*, fig. 7., which compoſe the ſides of the groove, have elliptic holes for their ſcrews *v*, ſo as to admit, when the ſcrews are ſlackened, of being puſhed inwards by the ſcrews *w*, which work in a lump of metal caſt with the part AA.

The large lathes which Mr. Maudſlay uſes in his manufactory, inſtead of being worked by the foot, as repreſented in fig. 1., are worked by hand; the wheel and fly-wheel which the men turn works by a ſtrap on another wheel, fixed to the ceiling directly over it; on the axis of this wheel is a larger one, which turns another ſmall wheel or pulley, fixed to the ceiling, directly over the mandrel of the lathe; and this laſt has on its axis a larger one which works the mandrel D, by a band of catgut. Theſe latter wheels are fixed in a frame of caſt-iron, moveable on a joint; and this frame has always a ſtrong tendency to riſe up, in conſequence of the action of a heavy weight; the rope from which, after paſſing over a pulley, is faſtened to the frame: this weight not only operates to keep the mandrill-band tight, when applied to any of the grooves therein, but always makes the ſtrap between the two wheels on the ceiling fit. As it is neceſſary that the workman ſhould be able to ſtop his lathe, without the men ſtopping who are turning the great wheel, there are two pulleys or rollers (on the axis of the wheel over the lathe), for the ſtrap coming from the other wheel on the ceiling; one of theſe pulleys, called the *dead pulley*, is fixed to the axis and turns with it, and the other which ſlips round it, is called the *live pulley:* theſe pulleys are put cloſe to each other, ſo that by ſlipping the ſtrap upon the *live pulley*, it will not turn the axis; but if it is ſlipped on the other it will turn with it: this is effected by an horizontal bar, with two upright pins in it, between which the ſtrap paſſes. This bar is moved in ſuch a direction as will throw the ſtrap upon the live pulley, by means of a ſtrong bell-ſpring; and in a contrary direction it is moved by a cord faſtened to it, which paſſes over a pulley, and hangs down within reach of the workman's hand: to this cord is faſtened a weight, heavy enough to counteract the bell-ſpring, and bring the ſtrap up to the dead pulley, to turn the lathe; but when the weight is laid upon a little ſhelf, prepared for the purpoſe, the ſpring will act and ſtop it.

Mr. Maudſlay has likewiſe ſome additional apparatus for cutting the teeth of wheels, in which the face of the mandrel D, fig. 1., has ſeventeen concentric circles upon it, each divided into a different number of equal parts, by ſmall holes. There is a thin ſtop, *x*, fig. 1., which moves round on a ſcrew, fixed in the ſtandard F: this ſtop is made of thin ſteel, and is ſo fixed, that when it is turned up, and its point inſerted into any of the diviſions of the mandrel, it will have a ſufficient ſpring to keep it there: the wheel to be cut is faſtened, by means of a chuck, to the ſcrew *n*, and after it has been turned, and brought to the proper ſhape, the reſt J is to be taken away, and the ſlide-tool ſubſtituted: a ſquare bar is then put into the two holders, *bb*, fig. 7.;

this bar has two branches for holding the ends of a ſpindle, near one end of which is a pulley, and at the other are four chiſels; fixed perpendicularly into the ſpindle for cutting out the teeth (inſtead of the circular ſaw commonly uſed): the pulley is turned (with the intervention of ſeveral wheels to augment the velocity) by the ſame great wheel as the lathe, with 7300 revolutions per minute; the mandrel is then fixed by the ſtop *x*, fig. 1., and the cutter advanced towards the wheel, by the ſcrew *c*, fig. 7. When it has cut that tooth, the cutter is withdrawn, and the mandrel turned to another diviſion, and a tooth is cut again as before. At that part of the frame of the cutting-ſpindle where the bar which is fixed in the holders of the ſlide-tool connects with the two branches there is a joint, by which the cutting-ſpindle can be ſet in an inclining poſition, for cutting oblique teeth like thoſe which are to work with an endleſs ſcrew. The great velocity with which this ſpindle turns ſoon generates, by friction and reſiſtance, a degree of heat ſufficient to expand it very ſenſibly: but this ingenious mechaniſt, foreſeeing ſuch a circumſtance, has judiciouſly compenſated for it in his conſtruction, by making the ſpindle ſo ſhort as to play looſely in its ſockets at the commencement of the motion; but after a few ſeconds the expanſion is ſuch as to cauſe the whole to fit together as it ought to do, and the work of cutting to proceed with accuracy and ſafety.

Another ſkilful mechanic, Mr. *Smart*, of Ordnance Wharf, Weſtminſter, whoſe chimney-cleanſers, and ſaws, have been noticed in earlier parts of this volume, has made ſome very uſeful improvements in the art of turning, and particularly has ſtruck out a ſimple method of turning cylinders and cones, in wood. The figures to illuſtrate his turning machinery are given in pl. XXVI. (figs. 3. 4.), where the legs or ſtiles L, the puppets A, B, the cheeks *o*, *o*, the pikes and ſcrews, M, N, R, with the handle D, are but ſlightly varied from the uſual conſtruction. Round the mandrel E paſſes a band F, F, which alſo encompaſſes a large wheel not ſhewn in the figure; and when this large wheel is turned round with moderate ſwiftneſs, it communicates a rapid velocity to the mandrel E, and the long piece of wood G, which is propoſed to be made cylindrical. This piece is previouſly hewn into an octagonal form. The cutting-frame H contains a ſharp iron tool, which is to anſwer the purpoſe of the common turning-gouge, and which is fitted into the frame ſo as to project a little beyond its inner part, after the manner of a carpenter's plane-iron for round or ogee work. Then, while the piece G is turning ſwiftly round by a man working at the great wheel, another man puſhes the frame H gently on from L towards M, the lower part of that frame fitting between the cheeks *o*, *o*, and ſliding along between them. By this proceſs, the piece G is reduced to a cylinder, moderately ſmooth; and, in order to render the ſmoothneſs as complete as need be, a ſecond cutter, and its frame I, adapted to a rather ſmaller cylinder than the former, is puſhed along in like manner from I to M. This operation may be performed with ſuch ſpeed, that a very accurate cylinder of 6 feet long, and 4 inches diameter, may be fixed to the lathe and turned in much leſs than a minute.

Mr. Smart turns a conical end to one of theſe cylinders with great facility, by means of a cutting-blade fixed in an iron hollow conical frame K, the ſmaller end of which admits the pike from the ſcrew S (fig. 4.), to which one end of the cylinder G is attached: as the cylinder turns rapidly round, the cutter K is conducted gently along it by means of the hollow frame, and ſoon gives the conical ſhape to the end of the cylinder, as required.

Some important directions for turning ſcrews, ovals, cubes, roſe-work, ſwaſh-work, &c. may be ſeen in *Moxon's Mechanic Exerciſes*: the inſertion of them here would occupy more room than is compatible with the plan of this work. See alſo, "Tour pour faire ſans Arbre toutes Sortes de Vis, par M. *Grandjean*," in "Recueil des Machines et Inventions, approuvées par l'Acad. Roy. des Sciences," tom. v.; and Mr. *Healy*'s method of cutting ſcrews in the common turning-lathe, in Tilloch's Phil. Mag. vol. xix.

WATCH, a ſmall portable machine for meaſuring time; having its motion commonly regulated by a ſpiral ſpring. Perhaps, ſtrictly ſpeaking, watches are all ſuch movements as *ſhew* the parts of time; as clocks are ſuch as *publiſh* them, by ſtriking on a bell, &c. But commonly, the term watch is appropriated to ſuch as are carried in the pocket; and clock to the large movements, whether they ſtrike the hour or not.

Spring or *Pendulum* WATCHES ſtand pretty much on the ſame principle with pendulum clocks. For if a pendulum, deſcribing ſmall circular arcs, make vibrations of unequal lengths, in equal times, it is becauſe it deſcribes the greater arc with a greater velocity; ſo a ſpring put in motion, and making greater and leſs vibrations, as it is more or leſs ſtiff, and as it has a greater or leſs degree of motion given it, performs them nearly in equal times. Hence, as the vibrations of the pendulum had been applied to large clocks, to rectify the inequality of their motions; ſo, to correct the unequal motions of the balance in watches, a ſpring is added, by the iſochroniſm of whoſe vibrations the correction is to be affected. The ſpring is uſually wound into a ſpiral; that, in the little compaſs allotted it, it may be as long as poſſible; and may have ſtrength enough not to be maſtered, and dragged about, by the inequalities of the balance it is to regulate. The vibrations of the two parts, viz. the ſpring and the balance, ſhould be of the ſame length; but ſo adjuſted, as that the ſpring, being more regular in the length of its vibrations than the balance, may occaſionally communicate its regularity to the latter.

Striking WATCHES are ſuch as, beſides the proper watch-part for meaſuring of time, have a clock-part for ſtriking the hours, &c.

Repeating WATCHES are ſuch as by pulling a ſtring, &c. repeat the hour, quarter, or minute, at any time of the day or night. This repetition was the invention of Mr. Barlow, and firſt put in practice by him in larger movements or clocks about the year 1676. The contrivance immediately ſet the other artiſts to work, who ſoon contrived divers ways of effecting the ſame: but its application to pocket-watches was not known before king James the Second's reign; when the ingenious inventor above mentioned, having directed Mr. Thompſon to make a repeating watch, was ſoliciting a patent for the ſame. The talk of a patent engaged Mr. Quare to reſume the thoughts of a like contrivance, which he had had in view ſome years before: he now effected it; and being preſſed to endeavour to prevent Mr. Barlow's patent, a watch of each kind was produced before the king and council; upon trial of which, the preference was given to Mr. Quare's. The difference between them was, that Barlow's was made to repeat by puſhing in two pieces on each ſide the watch-box; one of which repeated the hour, and the other the quarter: whereas Quare's was made to repeat by a pin that ſtuck out near the pendant, which being thruſt in (as now it is done by thruſting in the pendant itſelf), repeated both the hour and quarter with the ſame thruſt.

Of the Mechaniſm of a WATCH, properly ſo called. Watches, as well as clocks, are compoſed of wheels and pinions, and a regulator to direct the quickneſs or ſlowneſs of the wheels, and of a ſpring which communicates motion to the whole machine. But the regulator and ſpring of a watch are vaſtly inferior to the weight and pendulum of a clock, neither of which can be employed in watches. Inſtead of a pendulum, therefore, we are obliged to uſe a balance (pl. XXXIII. fig. 1.) to regulate the motion of a watch; and a ſpring (fig. 2.) which ſerves inſtead of a weight, to give motion to the wheels and balance.

The wheels of a watch, like thoſe of a clock, are placed in a frame formed of two plates and four pillars. Fig. 3. repreſents the inſide of a watch, after the plate (fig. 4.) is taken off. A is the barrel which contains the ſpring (fig. 2.); the chain is rolled about the barrel, with one end of it fixed to the barrel A, (fig. 5.), and the other to the fuſee B.

When a watch is wound up, the chain which was upon the barrel winds about the fuſee, and by this means the ſpring is ſtretched; for the interior end of the ſpring is fixed by a hook to the immoveable axis about which the barrel revolves; the exterior end of the ſpring is fixed to the inſide of the barrel, which turns upon an axis. It is therefore eaſy to perceive how the ſpring extends itſelf, and how its elaſticity forces the barrel to turn round, and conſequently obliges the chain which is upon the fuſee to unfold and turn the fuſee: the motion of the fuſee is communicated to the wheel C (fig. 5.); then, by means of the teeth, to the pinion *c*, which carries the wheel D; then to the pinion *d*, which carries the wheel E; then to the pinion *e*, which carries the wheel F; then to the pinion *f*, upon which is the balance-wheel G, whoſe pivot runs in the pieces A called the *potance*, and B called a *follower*, which are fixed on the plate fig. 4. This plate, of which only a part is repreſented, is applied to that of fig. 3. in ſuch a manner that the pivots of the wheels enter into holes made in the plate, fig. 3. Thus the impreſſed force of the ſpring is communicated to the wheels: and the pinion *f* being then connected to the wheel F, obliges it to turn (fig. 5.) This wheel acts upon the palettes of the verge 1, 2 (fig. 1.), the axis of which carries the balance HH (fig. 1.). The pivot I, in the end of the verge, enters into the hole *c* in the potance A (fig. 4.). In this figure the palettes are repreſented; but the balance is on the other ſide of the plate, as may be ſeen in fig. 6. The pivot 3 of the balance enters into a hole of the cock BC (fig. 7.), a perſpective view of which is repreſented in fig. 8. Thus the balance turns between the cock and the potance *c* (fig. 4.), as in a kind of cage. The action of the balance-wheel upon the palettes 1, 2 (fig. 1.), is the ſame with what we have deſcribed with regard to the ſame wheel in the clock; *i. e.* in a watch, the balance-wheel obliges the balance to vibrate backwards and forwards like a pendulum. At each vibration of the balance a palette allows a tooth of the balance-wheel to eſcape; ſo that the quickneſs of the motion of the wheels is entirely determined by the quickneſs of the vibrations of the balance; and theſe vibrations of the balance and motion of the wheels are produced by the action of the ſpring.

But the quickneſs or ſlowneſs of the vibrations of the balance depend not ſolely upon the action of the great ſpring, but chiefly upon the action of the ſpring *a*, *b*, *c*, called *the ſpiral ſpring* (fig. 9.), ſituated under the balance H, and repreſented in perſpective (fig. 6.). The exterior end of the ſpiral is fixed to the pin *a* (fig. 9.). This pin is applied near the plate in *a* (fig. 6.); the interior end of the ſpiral is fixed by a peg to the centre of the balance. Hence if the balance is turned upon itſelf, the plates remaining immoveable, the ſpring will extend itſelf, and make the balance perform one revolution. Now, after the ſpiral is thus extended, if the balance be left to itſelf, the elaſticity of the ſpiral will bring back the balance, and in this manner the alternate vibrations of the balance are produced.

In fig. 5. all the wheels above deſcribed are repreſented in ſuch a manner, that it may be eaſily perceived at firſt ſight how the motion is communicated from the barrel to the balance.

In fig. 10. are repreſented the wheels under the dial-plate by which the hands are moved. The pinion *a* is adjuſted to the force of the prolonged pivot of the wheel D (fig. 5.), and is called a *cannon pinion*. This wheel revolves in an hour. The end of the axis of the pinion *a*, upon which the minute-hand is fixed, is ſquare; the pinion (fig. 10.) is indented into the wheel *b*, which is carried by the pinion *a*. Fig. 11. is a wheel fixed upon a barrel, into the cavity of which the pinion *a* enters, and upon which it turns freely. This wheel revolves in twelve hours, and carries along with it the hour-hand.

Such in brief is the general mechaniſm of a watch: to treat the ſubject to the extent its importance demands would require a volume: ſome parts of the conſtruction are further explained under the words BALANCE and SCAPEMENT in this volume; but for more ample information the reader muſt conſult ſome of the treatiſes mentioned in our general catalogue of writings on CLOCK-WORK.

Mr. Elliot, of Clerkenwell, has lately invented a very ſimple *repeating* watch; in which the motion is performed with much fewer parts than in the uſual conſtruction, by which means he is enabled to reduce the price ſo low as eight guineas for a good repeater on this principle, or to add the repeating-work to another watch for three.

The method by which this repeater is ſo much ſimplified is by the uſe of a ſingle part, ſo contrived as to perform the operations of ſeveral: this is, a flat ring, or centreleſs wheel, of nearly the ſame diameter as the watch, ſupported in its place, ſo as to admit of circular motion, by four grooved pulleys placed round its external circumference, in the ſame manner as the part in common clocks which denotes the moon's age. This part is put in motion by turning the pendant, whoſe extremity is formed into a ſmall vertical wheel, which works in teeth cut on the external part of the flat ring for almoſt a third of its circumference. The lower part of the ring contains the pins, at right angles to its face, which lift the hammers for ſtriking the hours and quarters; the internal part of the ring contains indentations of regularly increaſing depths, which, receiving the tails of the levers, whoſe other extremities are preſſed by their ſprings againſt the hour-ſnail and the quarter-ſnail, is by them prevented from moving beyond a certain degree proper for the time: after the pendant is turned, the ring is brought back to its firſt poſition, by a box-ſpring, round which a fine chain is coiled, whoſe extremity is connected with the inner part of the ring.

By turning the pendant to the left the hour is ſtruck, and by turning it to the right the quarters are repeated; and the returning ſpring juſt mentioned is made to operate in both directions, by its chain paſſing between two little pulleys, which on either ſide convert the direction of the chain to the line of traction of the ſpring.

Hence it is evident this ſingle flat ring performs all the following operations.

1. It receives the motion for ſtriking the hour from the pendant.
2. — The ſame for ſtriking the quarters.
3. It carries the pins, or teeth, which lift the hour-hammer.
4. — The ſame for the quarter-hammer.
5. It contains the indentations by which the hour-ſnail operates on it by its lever.
6. — The ſame, by which the quarter-ſnail operates on it.
7. It carries the part that recoils the movement which tells the hour to its firſt poſition.
8. It carries the part, for the ſame purpoſe, for the quarter-movement.
9. It contains a cavity, which moves over a fixed pin, that prevents the pendant from turning it too far.

In this ring, the ſame parts, in three inſtances, are made to perform double operations, by which ſimplicity of conſtruction is advanced, apparently to its greateſt extent.

WATCHMAN's Noctuary, the name given to an inſtrument lately contrived to remedy a great defect in an important branch of the police of great cities, that of *night-watching*. Every twenty-four hours furniſhes ſome inſtance of the inefficiency of the preſent ſyſtem, by the depredations which have been committed in the night, or by the fatal accidents which occur from a neglect of giving families timely warning in caſes of ſudden fires. A reſpectable magiſtrate (Samuel Day, Eſq. of Charter-houſe, Hinton, Somerſetſhire) has directed his attention to the application of a mechanical check upon the diſgence and regularity of watchmen, labourers, and all other claſſes of men whoſe duty requires that they ſhould attend at certain places at appointed times: the inſtrument he has invented for this purpoſe he calls a *Watchman's noctuary*, or *Labourer's regulator*.

The invention conſiſts principally of a large horizontal wheel, which is moved uniformly round every 12 hours by clock-work. The upper ſide of this wheel is divided by two circles, one within the other; the outer one, or periphery, having the hours and quarters marked on it, which may be called the lateral ſide; the inner circle having alſo a dial, which may be called the vertical one. The ſpace between theſe circles or dials is divided into cells, each cell correſponding with a quarter or half-hour of the different hours marked on the dials; and, if thought proper, the cells might be ſo multiplied, as that each would correſpond within a period of five minutes. Such is the upper ſide of the horizontal wheel, which may be made of copper, or tin, or various other materials, and is about 9 inches in diameter. The under ſide of the ſame has a braſs wheel with teeth, diameter 3½ inches, fixed to its central part; the teeth of which, letting in with thoſe of a ſmaller wheel or pinion, give motion in conſequence to the large horizontal wheel (of which it forms a part) by the motion it receives from the pinion. This pinion being ſet in motion by the common clock-work and a weight or ſpring, the revolution of the horizontal wheel is completed once in twelve hours, and thus, regularly going round, will at all times ſhew the time of day or night. As it moves round it carries the cells above-mentioned under a kind of chink, juſt large enough to receive a token of about the ſize of a farthing. This chink ſinks down from an external braſs box, which is ſufficiently large to admit a man's fingers to drop in the token by an external aperture or mouth of the chink, the token being directed perpendicularly through this chink into ſuch cell as is immediately under it, and which muſt correſpond with the time of night or day. The head of the caſe of the machine has double doors in front; the outward door covers the whole face together, leaving a ſufficient ſpace above the horizontal wheel for examining the tokens and taking them from the cells, or for removing the wheel when neceſſary. A ſmaller door opens in this large one upon the braſs box above-mentioned, the opening of which belongs ſolely to the watchman, or ſuch other perſon as may be required to uſe the ſame, for the purpoſe of ſeeing the time and dropping his tokens, a minute-dial alſo being placed under the hour-index. If it be found more convenient, a common dial-plate, to ſhew the hours and minutes, may be placed inſtead of the minute-dial. The great outer door firſt mentioned is to be opened only by the inſpector or examiner of the tokens, and ought to be well ſecured; but, for greater ſafety, both againſt thieves and weather, there is an inſide door, in which the fore-mentioned braſs box is fixed; and this inner door being opened, throws into view the horizontal wheel, for the purpoſe juſt ſpecified. Theſe are the eſſential parts of the invention: the different appendages may be variouſly modified.

One ſuch inſtrument as this being placed at each end of a watchman's round, it will be aſcertained how the man continued his movements through the night, to a nicety of 10 minutes (or leſs if required) at any period of the watch; and the ſlighteſt irregularity or omiſſion will be detected the next morning by the perſon whoſe office it ſhall be to open the machine. No trick or fraud on the watchman's part can counteract the movement of the horizontal wheel comprising the cells into which the tokens are to be dropped; each cell is, by this contrivance, like time itſelf, irrevocable when paſt: the watchman has no command over it, and the whole will be a kind of ſpeaking witneſs of his diligence and fidelity in going his rounds, anſwering the next morning to the exact periods he either was or ought to have been there.

By this means the calls of the watchmen, which were only inſtituted for the purpoſe of his giving notice of being on his duty, will be ſuperſeded; and a conſiderable expence of animal exertion will be ſaved to the individual, which might better be converted into that of going his rounds twice, where he now only goes once. Warnings to the nightly thief of timely attack or retreat will likewiſe be taken away; and if inſtead of an open, the watchman was to carry a dark, lanthorn, the robber would have no ſecurity whatever in calculating the moment of his depredation, and might be detected in the very outſet of his attack, as the ſlighteſt ſound would alarm the watchman walking in ſilence, and not drowning diſtant noiſe by that of his own voice.

Of the objections to this new mode of ameliorating the watching of cities, the only one ſeems to be the expence of the time-pieces; and conſidering the number which the larger pariſhes will have occaſion for, this expence will be ſuppoſed important; but let it be conſidered that it will never amount to more than three-pence in the pound of a rate on houſes, and that the firſt will be the ſole expence—probably to be ſaved by diminiſhing the number of patroles to one half (or leſs) of what they now are. But trifling indeed will be the expence when compared with the loſſes ſuſtained by the public in depredations, which, according to a late work on the police of the metropolis, amounts to two millions and upwards annually.

The beſt ſituation for theſe machines will be at each end of a watchman's round, perhaps certain rounds will require three. They ought to ſtand in a convenient receſs in the ſtreet, ſecured by rivetings of iron, or let into a wall, or placed on a ſtrong bracket within the iron railing of an area; and, if the dial-plates were ſuffered to appear, would be uſeful in the day as well as in the night: as an eight-day clock it would require no attention to its movement but once a week, and the morning inſpector might attend to the ſlight duty of winding it up.

The annual expence of keeping it in repair is too trifling to be taken notice of.

The ſame machine will anſwer in cuſtom-houſes, ware-houſes, banking-houſes, manufactories, bleaching-grounds, and every place where watching or other attendance, to be uſeful muſt be exact: even ſentinels on military duty might be required to leave tokens as memorials of their vigilance.

Mr. Day has, we underſtand, obtained the uſual patent for ſecuring to himſelf the right of making and ſelling this inſtrument; yet ſurely not to the excluſion of others invented for the ſame purpoſe: for the late Marquis of Exeter informed the public more than two years ago, through the medium of Nicholſon's Philoſophical Journal, that a clock for a ſimilar purpoſe had been invented by Meſſrs. Boulton and Watt of Birmingham, which coſts no more than thirty ſhillings. His lordſhip had then had two of them at Burleigh-Hall more than four years; and he gives the following deſcription of them: "They go eight days, and have a face like a clock, but do not ſtrike. The dial goes round, and the hour-finger is fixed: round the edge of the dial are moveable iron pins, correſponding with the quarters in each hour. A ſmall hammer placed behind the hour-finger, when moved downwards, puſhes into the dial one of the pins which happens to be under it at the time, which pin remains ſo abaſed until the dial nearly returns to the ſame place, when by an incloſed plane the pin is raiſed up into its firſt poſition. This gives time to have the machine examined in the morning, to ſee how many pins have been ſtruck, and at what time they were puſhed downwards. The hammer is moved by the pulling of a chain with a handle, like houſe-door bells, which, by cranks and wires, is attached to it. I have one in my library, the handle is out of doors. The other machine is placed in a building at the other end of my premiſes."

WATER-MILLS, the general term by which all kinds of mills which have a ſtream of water for their firſt mover, are deſignated. The term is alſo ſometimes applied to machines driven by wind for the purpoſe of draining water out of fen lands; but it is with more propriety confined to the preceding acceptation.

It is not our intention in the preſent article to enter minutely into the deſcription of the various kinds of machinery driven by water as an active power, but to confine ourſelves to a few general remarks upon the conſtruction of that part only which is eſſential to water-mills, the *water-wheel:* for the axis of this wheel may be employed to tranſmit the force impreſſed upon it to any ſpecies of machinery. A conciſe view of the theory of water-wheels, together with a tolerably copious ſtatement of the experiments and reſults of Smeaton, have been laid before the reader in book iv. of our firſt volume: we propoſe now to preſent ſome obſervations on their ſhape, magnitude, and velocity.

The moſt general diviſion of water-wheels is into two kinds, reſulting from the manner in which the fluid is made to act: when water is made to act by its weight, it is delivered from the ſpout as high on the wheel as poſſible, that it may continue long to preſs it down; but when it is made to *ſtrike* the wheel, it is delivered as low as poſſible, that it may have previouſly acquired a great velocity: thus are the wheels ſaid to be *overſhot* or *underſhot*. The four kinds of wheels mentioned in art. 467. vol. i. belong, in fact, to one or other of theſe general diviſions.

1. An *overſhot-wheel* is nothing but a frame of open buckets ſo diſpoſed round the rim of a wheel as to receive the water delivered from a ſpout in ſuch a manner that one ſide of the wheel is loaded with water while the other is empty: of conſequence the loaded ſide muſt deſcend; and by this motion the fluid runs out of the lower buckets, while the empty buckets of the riſing ſide of the wheel, in their turn, come under the ſpout, and are filled with water. A ſlight inſpection of the figure of an overſhot water-wheel, in plate XVIII. of our firſt volume, will convince the ſtudent of the impoſſibility of conſtructing the buckets ſo as to remain completely filled with water till they reach the bottom of the wheel: indeed, if the buckets are formed by partitions directed to the axis of the wheel, the whole water muſt be run out by the time that they have deſcended to the level of the axis; and, of conſequence, there muſt be a great diminution in the mechanical effect of the wheel. Millwrights have, therefore, turned their chief attention to the determination of a form for the buckets which ſhall enable them to retain the water along a great portion of the circumference of the wheel. It would require much more room than we can aſſign to this article, to deſcribe half the contrivances which have been propoſed; we ſhall therefore only men-

tion one or two of the beſt, as deſcribed by Dr. Robiſon in the Encyclopedia Britannica.

In fig. 11. pl. XXXII. AM is part of the ſhrouding or ring of buckets of an overſhot containing 40 buckets. GOFABCD is the form of one of theſe buckets. The ſhoulder AB of the bucket ſhould be one half of AE, the depth of the ſhrouding; AF ſhould be $\frac{1}{7}$ more than AE. The arm BC of the bucket muſt be ſo inclined to AB, that HC may be $\frac{5}{6}$ of AE; and CD, the wriſt of the bucket, muſt make ſuch an angle with BC n, the direction of the arm, that D n may be $\frac{1}{5}$ of E n.

From this conſtruction it follows, that the area HABC is very nearly equal to DABC: ſo that the water which will fill the ſpace HABC will all be contained in the bucket when it ſhall come into ſuch a poſition that AD is a horizontal line; and the line AB will then make an angle of nearly 35° with the vertical, or the bucket will be 35° from the perpendicular paſſing through the axis of motion. If the bucket deſcend ſo much lower that one-half of the water runs out, the line AB will make an angle of about $24\frac{1}{2}$° with the vertical. Therefore the wheel, filled to the degree now mentioned, will *begin* to loſe water at about $\frac{1}{3}$ of the diameter from the bottom, and *half of the water will be diſcharged* from the loweſt bucket about $\frac{1}{24}$th of the diameter further down. Had a greater proportion of the buckets been filled with water when they were under the ſpout, the diſcharge would have begun at a greater height from the bottom, and a greater portion of the whole fall of water would be loſt. The loſs by the preceding conſtruction is leſs than $\frac{1}{15}$th (ſuppoſing the water to be delivered into the wheel quite at its top), and may be eſtimated at about $\frac{1}{12}$th; for the loſs is, as the verſed ſine of the angle which the radius of the bucket makes with the vertical. The verſed ſine of 35° is ·18085, nearly $\frac{1}{5}$th of the radius, or $\frac{1}{10}$th of the diameter. Had only $\frac{1}{2}$ of this water been ſupplied to each bucket as it paſſes the ſpout, it would have been retained for 10° more of a revolution, and the loſs of fall would have only been about $\frac{1}{19}$th.

A very conſiderable improvement in the conſtruction of the bucket has been made by Mr. Robert Burns of Cartſide, Renfrewſhire. He divides the bucket by a partition *m* B, of ſuch a height, that the portions of the bucket on each ſide of it may be of equal capacity. Dr. Robiſon juſtly obſerves, that this principle is ſuſceptible of conſiderable extenſion, and recommends two or more partitions, particularly when the wheel is made of iron. By this means the fluid is retained longer in the lower buckets, and when there is a ſmall ſupply of water, it may be delivered into the outer portion of the bucket, which, being at a greater diſtance from the centre of motion, increaſes the power of the water to turn the wheel. The doctor adviſes that the rim of the wheel, and conſequently the breadth of the buckets, ſhould be pretty large, in order that the quantity of water which they receive from the ſpout may not nearly fill the bucket. The ſpout which conveys the water ſhould be conſiderably narrower than the breadth of the bucket; and the ſhoulder AB ſhould be perforated with a few holes, in order to prevent the water from being lifted up by the aſcending buckets. The diſtance of the ſpout from the receiving bucket ſhould, in general, be two, three, or four inches, that the water may be delivered with a velocity a little greater than that of the rim of the wheel; otherwiſe the wheel will be retarded by the impulſe of the buckets againſt the ſtream, and much power would be loſt by the water daſhing over them.

With reſpect to variations in the fall of water, ſince the active preſſure is meaſured by the pillar of water reaching from the horizontal plane where it is delivered on the wheel, to the horizontal plane where it is ſpilled by the wheel, it has been concluded, that preſſure muſt be proportional to the wheel; and therefore the water muſt be delivered as high and retained as long as poſſible. This maxim, however, is ſubject to limitations, and is not perhaps ſtrictly conſiſtent with ſound theory. When the fall is exceedingly great, a wheel of an equal diameter becomes enormouſly big and extremely expenſive. In caſes like this where we are unwilling to loſe any part of the force of a fall-ſtream, the beſt form of a bucket-wheel is an inverted chain-pump.

The velocity of an overſhot-wheel is a matter deſerving of great care and attention; and different authors have arrived at very oppoſite concluſions reſpecting it. The moſt accurate ſeems to be that an overſhot-wheel does the more work, as it moves ſlower: the popular reaſoning adduced to prove this has been of the following kind. Suppoſe that a certain wheel has 30 buckets, and that 6 cubic feet of water are delivered in a ſecond on the top of the wheel, and diſcharged, without any loſs by the way, at a certain height from the bottom of the wheel. Let this be the caſe whatever is the rate of the wheel's motion, the buckets being of a ſufficient capacity to hold all the water which falls into them. Suppoſe this wheel employed to raiſe a weight of any kind, water, for inſtance, in a chain of 30 buckets, to the ſame altitude and with the ſame velocity. Suppoſe, further, that when the load on the riſing ſide of the machine is one-half of that on the wheel, the wheel makes 4 revolutions in a minute, or one turn in 15 ſeconds. During this time 90 cubic feet of water will have flowed into the 30 buckets, and each have received 3 cubic feet. In that caſe, each of the riſing buckets contains $1\frac{1}{2}$ feet; and 45 cubic feet are delivered into the upper ciſtern during one turn of the wheel, and 180 cubic feet in one minute.

Now, ſuppoſe the machine ſo loaded, by making the riſing buckets more capacious, that it makes only 2 turns in a minute, or 1 turn in 30 ſeconds; then each deſcending bucket muſt contain 6 cubic feet of water. If each bucket of the riſing ſide contained 3 cubic feet, the motion of the machine would be the ſame as before. This is a point none will controvert. When two pounds are ſuſpended to one end of a ſtring which paſſes over a pulley, and one pound to the other end, the velocity of deſcent of the two pounds will be the ſame with that of a four-pound weight, which is employed in the ſame manner to draw up two pounds. Our machine would therefore continue to make four turns in a minute, and would deliver 90 cubic feet during each turn, and 360 in a minute. But, by ſuppoſition, it is making only two turns in a minute; which *muſt* proceed from a greater load than 3 cubic feet of riſing water in each riſing bucket. The machine muſt, therefore, be raiſing *more* than 90 feet of water during one turn of the wheel, and *more* than 180 in a minute.

Thus it appears that if the machine is turning twice as ſlow as before, there is *more than twice the former quantity* in the riſing buckets; and more will be raiſed in a minute by the ſame expenditure of power. In like manner, if the machine go three times as ſlow, there muſt be *more than three times* the former quantity in the riſing buckets, and more work will be done.

But further we may aſſert, that the *more* we retard the machine to a certain practical extent, by loading it with more work of a ſimilar kind, the greater will be its performance; and the truth of the aſſertion may be thus demonſtrated: Let us call the firſt quantity of water in the riſing bucket, Q; the water raiſed by four turns in a minute will be $4 \times 30 \times Q = 120\,Q$. The quantity in this bucket, when the machine goes twice as ſlow, has been ſhewn to be greater than $2\,Q$; call it $2\,Q + x$; the water raiſed by two turns in a minute will then be $2 \times 30 \times (2\,Q + x) = 120\,Q + 60\,x$. Suppoſe, next, the machine to go 4 times as ſlow, making but one turn in a minute; the riſing bucket muſt now contain more than twice the quantity $2\,Q + x$, or more than $4\,Q + 2\,x$, call it $4\,Q + 2\,x + y$. The work done by one turn in a minute will now be $30 \times (4\,Q + 2\,x + y) = 120\,Q + 60\,x + 30\,y$. By ſuch an induction of the work accompliſhed, with any rates of motion we chooſe, it is evident that the performance of the machine increaſes with every diminution of its velocity that is produced by the mere addition of a ſimilar load of work, or that it does the more work the ſlower it goes. This however is abſtracting from the effects of the friction upon the gudgeons of the wheel, a cauſe of reſiſtance which increaſes with the load, though not in the ſame ratio.

We have alſo ſuppoſed the machine to be in its ſtate of permanent uniform motion. If we conſider it only in the beginning of its motion, the reſult is ſtill more in favour of ſlow motion: for, at the firſt action of the moving power, the inertia of the machine itſelf conſumes part of it, and it acquires its permanent velocity by degrees, during which the reſiſtances ariſing from the work, friction, &c. increaſe, till they exactly balance the preſſure of the water; and after this the machine no longer accelerates. Now, the greater the power and the reſiſtance ariſing from the work are, in proportion to the inertia of the machine, the ſooner, it is obvious, will it arrive at its ſtate of permanent velocity.

The preceding diſcuſſion is ſufficient to demonſtrate, in general, the advantage of ſlow motion; but does not, it is confeſſed, point out in any degree the relation between the rate of motion and the work performed; nor even the principles on which it depends. This, however, is not neceſſary for the improvement of practical mechanics: but it is ſufficiently manifeſt that there is not, in the nature of things, a maximum of performance attached to any particular rate of motion, which ſhould, on that account, be preferred. All, therefore, we have to do, is to load the machine, and thus to diminiſh its ſpeed, unleſs other phyſical circumſtances throw obſtacles in the way: but there are ſuch obſtacles; for in all machines there are ſmall inequalities of action which are unavoidable. In the action of a wheel and pinion, though made with the utmoſt judgment and care, there are ſuch inequalities. Theſe increaſe by the changes of form occaſioned by the wearing of the machine; and much greater inequalities ariſe from the ſubſultory motions of cranks, ſtampers, and other parts which move unequally or reciprocally. Now, a machine may be ſo loaded as juſt to be in equilibrio with its work in the favourable poſition of its parts; and when this changes into one leſs favourable, the machine may ſtop, or at all events hobble, and work very irregularly: thus, the rubbing parts bear long on each other, with enormous preſſures, cut deep into one another, and greatly augment friction; ſo that ſuch ſlow motions as theſe muſt be avoided. A little more velocity enables the machine to overcome thoſe increaſed reſiſtances by its inertia, or the great quantity of motion inherent in it: great machines poſſeſs this advantage in a ſuperior degree, and will, conſequently, work ſteadily with a ſmaller velocity.

M. de Parcieux, the inventor of the areometer deſcribed in arts. 401, &c. vol. i. was, we believe, the firſt who deduced both from theory and experiment, the important reſult that the work done by a water-wheel was increaſed by diminiſhing its velocity. His diſſertations on this ſubject were firſt inſerted in *Mém. Paris. Acad. Sciences*, 1754: but lately the ſubſtance of them has appeared in various places. This philoſopher made experiments upon a ſmall wheel 20 inches in diameter, furniſhed with 48 buckets, which received the water like a breaſt-wheel. On the axis of this wheel were placed cylinders of different ſizes, the ſmalleſt being 1 inch and the largeſt 4 inches in diameter, around which was wrapped a cord, with a weight attached to it. When the one-inch cylinder was uſed, a weight of 12 ounces was elevated to the height of 69 inches and 9 lines; and a weight of 24 ounces was elevated 40 inches. When the four-inch cylinder was employed, a weight of 12 ounces was raiſed to the altitude of 87 inches and 9 lines, and a weight of 24 ounces to the height of 45 inches and 3 lines. From theſe reſults it is evident, that with the four-inch cylinder, when the motion was ſloweſt, the effect was greateſt, and that when a double weight was uſed, which diminiſhed the wheel's velocity, the weight was raiſed to more than half its former height.

The ſtudent, by turning to page 455 of our firſt volume, will ſee that Mr. Smeaton arrived at the ſame concluſion; although the greater extent and variety of his experiments enabled him to aſcertain that this general poſition was ſubject to a limitation varying with circumſtances, which a judicious engineer will always carefully diſcriminate.

2. *Underſhot-wheels.* To this claſs may be referred all wheels in which the motion of the water is more rapid than that of the float-boards of the wheel, ſo that the fluid impels them. The theory of this kind of water-wheels being ſo exceedingly imperfect, we can do little elſe than recommend to the ſtudent a cautious examination of the experiments of Smeaton. We have little to add to them here, except ſome reſults of De Parcieux and Boſſut, who have ſhewn by very good experiments that there is a ſenſible advantage gained by inclining the float-boards to the radius of the wheel about 20 degrees, ſo that each float-board when loweſt ſhall not be vertical, but have its edge turned up the ſtream about 20 degrees. Such inclination cauſes the water to heap up along the float-board, and act by its weight: the floats ſhould therefore be made much broader than the vein of water interrupted by them is deep.

Some engineers obſerving the great ſuperiority of overſhot above underſhot wheels, driven by the ſame expence of power, have propoſed to bring the water home to the lower part of the wheel on an even bottom, and to make the float-board no deeper than the aperture of the ſluice, which would permit the water to run out. The wheel they propoſe to be fitted with a cloſe ſole and ſides, exactly fitted to the end of this trough, ſo that if the wheel is at reſt, the water may be dammed up by the ſole and float-board: it will, therefore, preſs forward the float-board with the whole force of the head of water. But this, however ſpecious, cannot anſwer; for if we ſuppoſe no float-boards, the water will flow out at the bottom, propelled in the manner theſe gentlemen ſuppoſe; and it will be ſupplied from behind, the water coming *ſlowly* from all parts of the trough to the hole below the wheel. But now add the floats, and ſuppoſe the wheel in motion with the velocity that is expected. The other floats muſt drag into motion all the water which lies between them, giving to the greateſt part of it a motion far greater than it would have taken in conſequence of the preſſure of the water behind it; and the water out of the reach of the floats will remain ſtill, which it would not have done independent of the float-boards above it, becauſe it would have contributed to the expence of the hole. So that the motion which the wheel will acquire by this conſtruction muſt be widely different from what its projectors ſuppoſe.

As far as we are able to judge, the beſt way of delivering the water on an underſhot-wheel in a cloſe mill courſe is, to let it ſlide down a very ſmooth channel, without touching the wheel till near its bottom, where the wheel ſhould be exactly fitted to the courſe; or, to make the floats much broader than the depth of the vein of water that glides down the courſe, and allow it to be partly intercepted by the firſt floats, and heap up along them, acting by its weight, after its impulſe has been expended. If the bottom of the courſe be an arch of a circle deſcribed with a radius much greater than that of the wheel, the water which ſlides down will be thus gradually intercepted by the floats.

Attempts have been made to conſtruct water-wheels which receive the impulſe obliquely, like the ſails of a common wind-mill. This would, in many ſituations, be a great advantage. A very ſlow but deep river could in this manner be made to drive our mills; and although much power is loſt by the obliquity of the impulſe, the remainder may be very great. Dr. Robiſon ſpeaks of a wheel of this kind which was very powerful: it was a long cylindrical frame, having a plate ſtanding out from it about a foot broad, and ſurrounding it with a very oblique ſpiral, like a corkſcrew. This was immerſed about $\frac{1}{5}$th of its diameter (which was nearly 12 feet), having its axis in the direction of the ſtream. By the work which it was performing, it ſeemed more powerful than a common wheel which occupied the ſame *breadth* of the river. Its length was not leſs than 20 feet: had it been twice as much, it would have nearly doubled its power without occupying more of the waterway. Perhaps ſuch a ſpiral, continued quite to the axis, and moving in a hollow canal wholly filled by the ſtream, might be a very advantageous way of employing a deep and ſlow current.

In July, 1803, Mr. John Norton, of Rolls-buildings, took out a patent for an improvement in the conſtruction of water-mills, which is exactly this of the *ſpiral* wheel. How far an invention which had been publicly deſcribed ſeven years before in the Encyclopedia Britannica ought to be ſecured to Mr. Norton by a patent, we need not decide.

An underſhot-wheel, with oblique float-boards, was invented by the late Mr. Beſant of Brompton; on whoſe widow the Society for the Encouragement of Arts, &c. in 1801, conferred a reward of ten guineas: and, as it promiſes to be of great ſervice in many ſituations, we have given a repreſentation of it in pl. XXXV.

Fig. 7, A repreſents the body of the water-wheel, which is hollow, in the form of a drum, and is ſo conſtructed as to reſiſt the admiſſion of water. B is the axis on which the wheel turns. C the float-boards, placed on the periphery of the wheel, each of which is firmly fixed to its rim and to the body of the drum, in an oblique direction. D is the reſervoir that contains the water. E the penſtock, for regulating the quantity of water which runs to the wheel. F repreſents the current that has paſſed ſuch wheel.

Fig. 8. is a front view of the water-wheel, exhibiting the oblique direction in which the float-boards, C, are placed on the face of the wheel.

In the common water-wheels, more than half the quantity of that fluid paſſes from the gate through the wheel, without affording it any aſſiſtance: the action of the floats is reſiſted by the incumbent atmoſphere, at the moment when theſe leave the ſurface of the tail-water; and, as a ſimilar proportion of water with that which paſſed between the floats at the head neceſſarily flows between them at the tail, the motion of the wheel is greatly impeded. On the contrary, by Mr. Beſant's contrivance, no water can paſs, excepting that which acts with all its force on the extremity of the wheel; and, as the floats emerge from the water in an oblique direction, the weight of the atmoſphere is thus prevented from taking any effect. Although his new wheel is conſiderably heavier than thoſe conſtructed on the old plan, yet it revolves more eaſily on its axis; the water having a tendency to float it. Laſtly, repeated experiments have proved Mr. Beſant's wheel to be ſo decidedly ſuperior, that, when working in deep tail-water, it will carry weights in the proportion of three to one; on which account it will be particularly ſerviceable to tide-mills.

Mills with oblique floats are moſt uſeful for employing ſmall ſtreams which can be delivered from a ſpout with a great velocity. M. Boſſut has conſidered theſe with much attention, and has aſcertained the beſt modes of conſtruction. There are two which have nearly equal performances: 1. The vanes being placed like thoſe of a wind-mill round the rim of a horizontal or vertical wheel, and being made much broader than the vein of water which is to ſtrike them perpendicularly. By theſe means it will be ſpread about on the vane in a thin ſheet, and exert a preſſure nearly equal to twice the weight of a column whoſe baſe is the orifice of the ſpout, and whoſe height is the fall producing the velocity. Mills of this kind are much in uſe in the ſouth of Europe. The wheel is horizontal, and the vertical axis carries the millſtone; ſo that the mill is of the utmoſt ſimplicity, and this is no ſmall recommendation. Drawings of ſuch mills may be ſeen in Bockler, Leupold, and Belidor.

2. The vanes may be arranged round the rim of the wheel, not like the ſails of a windmill, but in planes inclined to the radii, though parallel to the axis, or to the planes paſſing through the axis. They may either ſtand on a ſole, like the oblique floats recommended by De Parcieux, as before mentioned; or they may ſtand on the ſide of the rim, not pointing to the axis, but aſide from it. This diſpoſition will admit of the ſpout being more conveniently diſpoſed either for a horizontal or a vertical wheel.

In the ſouthern provinces of France, where horizontal wheels are very generally employed, the float-boards are made of a curvilineal form, ſo as to be concave towards the ſtream. The Chevalier de Borda obſerves, that in theory a double effect is produced when the float-boards are concave, but that this effect is diminiſhed in practice from the difficulty of making the fluid enter and leave the curve in a proper direction. Notwithſtanding this difficulty, however, and other defects which might be pointed out, horizontal wheels with concave float-boards are always ſuperior to thoſe in which the float-boards are plane, and ſometimes to vertical wheels, when there is a ſufficient head of water. If the fall of water be five or ſix feet, a horizontal wheel with concave float-boards may be erected, whoſe maximum effect will be to that of ordinary vertical wheels as 3 to 2.

Floating WATER-MILLS. Although we are in this country provided with many contrivances, in which the different powers of water, ſteam, wind, and animal force, have been ſucceſsfully applied to the purpoſe of grinding corn into flour, yet we have not, till very lately, met with *floating water-mills* to be worked by tides or currents; and which are further deſigned to put in motion machinery adapted to any kind of manufacture.—Meſſrs. Polfreeman, of Long-acre, in conjunction with Meſſrs. Allen, Feſſenden, and Gray, have purchaſed the patent-right of Mr. Hawkins, and have lately completed one of thoſe mills, which, by permiſſion of the Board of Navigation, is ſtationed between London and Blackfriars-bridge. Such grant was obtained with the laudable view of reducing, if poſſible, the price of flour in the metropolis, and furniſhing a conſtant ſupply of that neceſſary article of ſubſiſtence. The ſimplicity of this invention renders a long deſcription ſuperfluous; as it conſiſts in merely applying the force of two or three water-wheels on each ſide of a barge, or any other veſſel better calculated to contain the interior part of the machinery. Were ſeveral mills of this kind to be ſtationed on the Thames, or any other river where the tide ebbs and flows, there would doubtleſs be numerous advantages reſult; for they would be far leſs expenſive than ſteam-engines in the original erection, beſides that they would lead to a conſiderable annual ſaving in the important article of coals.

Some other remarks connected with the ſubject of water-mills, will be found under the words FLOUR-MILLS, PENSTOCK, STREAM-MEASURERS, and TIDE-MILLS, in this volume: and chaps. 3. and 4. book iv. of our firſt volume. For further information, conſult *Fabre ſur les Machines Hydrauliques*, *Langſdorff's Handbuch der Maſchinenlehre, zweyter band*, or ſome other of the treatiſes mentioned in the general catalogue under the word MILL.

WEIGHING-ENGINES are often conſtructed in order to aſcertain the weight of the loads on waggons and carts paſſing along turnpike-roads. To prevent the roads from being too much worn, it has been found expedient to fix by an act of parliament a certain load for each breadth of wheel; and, that ſuch loads may not be exceeded, there are weighing-machines at ſeveral of the toll-gates, by which the loads of the ſeveral waggons, &c. paſſing through them can be determined.

In ſome of theſe machines the contrivance is ſuch, that the carriage whoſe load is to be weighed is lifted clear from the ground by means of four ſtrong chains and hooks attached to a large ſteel-yard, whoſe fulcrum is raiſed commonly by a combination of tooth and pinion-work, moved by a winch-handle: but it is far better to have the buſineſs performed by means of apparatus placed under a horizontal frame on which the carriage may be drawn.

The moſt compendious and economical machine of this kind that we have ſeen is one firſt uſed for weighing the riders of race-horſes, and afterwards applied to the more reputable ſervice of weighing loaded carriages.

Fig. 5. pl. XXXVII. is a plan of the machine; KLMN is the plan of a rectangular box, which has a platform lid or cover, of ſize ſufficient for placing the wheels of a cart or waggon. The box is about a foot deep, and is ſunk into the ground till the platform cover is even with the ſurface. In the middle of the box is an iron lever ſupported on the fulcrum pin *i k*, formed like the nail of a balance, which reſts with its edges on arches of hardened ſteel, firmly faſtened to the bottom of the box. This lever goes through one ſide of the box, and is furniſhed at its extremity with a hard ſteel pin *l m*, alſo formed to an edge below. In the very middle of the box it is croſſed by a third nail of hardened ſteel *g h*, alſo formed to an edge, but on the upper ſide. Theſe three edges are in one horizontal plane, as in a well-made balance.

In the four corners A, A′, E′, E, of the box are firmly fixed four blocks of tempered ſteel, having their upper ſurfaces formed into ſpherical cavities, well poliſhed, and hard tempered. ABCDE repreſents the upper edge of an iron bar of conſiderable ſtrength, which reſts on the cavities of the ſteel-blocks in A and E, by means of two hard ſteel ſtuds projecting from its under edge, and formed into obtuſe-angled points or cones. Theſe points are in a ſtraight line parallel to the ſide KN of the box. The middle part C of this crooked bar is faced with hard-tempered ſteel below, and is there formed into an edge parallel to AE and KN, by which it reſts on the upper edge of the ſteel pin *g h* which is in the lever. In a line parallel to AE, and on the upper ſide of the crooked bar ACE, are fixed two ſtuds or points of hardened ſteel B and D projecting upwards above half an inch. The platform-cover has four ſhort feet like a ſtool, terminated by hard ſteel ſtuds, which are ſhaped into ſpherical cavities, and well poliſhed. With theſe it reſts on the four ſteel points B, B′, D′, D. The bar ACE is kneed in ſuch a manner vertically, that the points A, B, D, E, and the edge C, are all in a horizontal plane. Theſe particulars will be better underſtood by looking at the elevation in fig. 6. What has been ſaid of the bar ACE muſt be underſtood as alſo ſaid of the bar A′CE′.

Draw through the centre of the box the line *a b c* perpendicular to the line AE, BD. It is evident that the bar ACE is equivalent to a lever *a b c*, having the fulcrum or axis AE reſting with its extremity C on the pin *h g*, and loaded at *b*. It is alſo evident that *a* C is to *a b* as the load on this lever to the preſſure which it exerts on the pin *g h*, and that the ſame proportion ſubſiſts between the whole load on the platform and the preſſure which it exerts on the pin *g h*. It will alſo appear, on an attentive conſideration, that this proportion is nowiſe deranged in whatever manner the load is placed on the platform. If very unequally, the two ends of the pin *g h* may be unequally preſſed, and the lever wrenched and ſtrained a little; but the total preſſure is not changed.

If there be now placed a balance or ſteel-yard at the ſide LK, in ſuch a manner that one end of it may be directly above the pin *l m* in the end of the lever EOF, they may be connected by a wire or ſlender rod, and a weight on the other arm of the balance or ſteel-yard may be put in equilibrio with any load that can be laid on the platform. A ſmall counterpoiſe being firſt hung on to balance the apparatus when unloaded, any additional weight will meaſure the load really laid on the platform. If *a b* be to *a c* as 1 to 8, and EO to EF alſo as 1 to 8, and if a common balance be uſed above, 64 pounds on the platform will be balanced by one pound in the ſcale, and every pound will be balanced by one-fourth of an ounce. This would be a very convenient partition for moſt purpoſes, as it would enable us to uſe a common balance and common weights to complete the machine: or it may be made with a balance of unequal arms, or with a ſteel-yard.

Some have thought to improve this inſtrument by uſing edges like thoſe of the nails of a balance inſtead of points. But unleſs made with uncommon accuracy, they will render the balance very dull. The ſmall deviation of the two edges A and E, or of B and D, from perfect paralleliſm to KN, is equivalent to a broad ſurface equal to the whole deviation. We imagine that, with no extraordinary care, the machine may be made to weigh within $\frac{1}{2000}$th of the truth, which is exact enough for any purpoſe in commerce.

It is neceſſary that the points be attached to the bars. Some have put the points at A and E in the blocks of ſteel faſtened to the bottom, becauſe the cavity there lodged water or dirt, which ſoon deſtroyed the inſtrument with ruſt. But this occaſions a change of proportion in the firſt lever by any ſhifting of the crooked bars; and this will frequently happen when the wheels of a loaded cart are puſhed on the platform. The cavity in the ſteel ſtud ſhould have a little rim round it, and it ſhould be kept full of oil. In a nice machine, a quarter of an inch of quickſilver would effectually prevent all theſe inconveniences.

The ſimpleſt and moſt economical form of this machine is to have no balance or ſecond ſteel-yard; but to make the firſt ſteel-yard EOF a lever of the firſt kind, viz. having the fulcrum between O and F, and allow it to project far beyond the box. The long or outward arm of this lever is then divided into a ſcale of weights, commencing at the ſide of the box.

A counterpoiſe muſt be choſen, ſuch as will, when at the beginning of the ſcale, balance the ſmalleſt load that will probably be examined. It will be convenient to carry on this ſcale by means of eke-weights hung on at the *extremity* of the lever, and to uſe but one moveable weight. By this method the diviſions of the ſcale will have always one value. The beſt arrangement is as follows: place the mark 0 at the beginning of the ſcale, and let it extend only to 100, if for pounds; or to 112, if for cwts.; or to 10, if for ſtones; and let the eke-weights be numbered 1, 2, 3, &c. Let the loweſt weight be marked on the beam. This is always to be added to the weight ſhewn by the operation. Let the eke-weights ſtand at the end of the beam, and let the general counterpoiſe always hang at 0. When the cart is put on the platform, the end of the beam tilts up. Hang on the heavieſt eke-weight that is not ſufficient to preſs it down. Now complete the balance by ſliding out the counterpoiſe. Suppoſe the conſtant load to be 312 lb. and that the counterpoiſe ſtands at 86, and that the eke-weight is 9; we have the load $= 986 + 312, = 1298$ lbs.

Weighing-*apparatus for goods*. Account of a new patent weighing-apparatus, invented by Mr. Hardie, of the Bengal warehouſe.

Although the operation of weighing goods for ſale or payment of duty requires to be conducted in the way beſt calculated to avoid miſtakes, yet we find that the ſeveral modes now in uſe are ſubject to frequent error through the complicated proceſs of reckoning the totals of hundreds, quarters, and pounds reſpectively, and retaining them in memory until called to the book-keepers, generally amidſt the buſtle of porters, carmen, cranemen, and others, at a time when the laborious exertions of lifting the heavy weights on and off the board render the weighers incapable of the cloſe attention which an accurate performance of the operation demands.

Experience ſhews, that in caſes of menſuration the uſe of a ſcale greatly contributes both to accuracy and diſpatch. Mr. Hardie, therefore, by means of giving the weights a certain form, has converted the operation of weighing into an operation of menſuration, for the purpoſe of obtaining the important advantages of a ſcale in the following manner, viz.

Fig. 1. pl. XXXII. Plan of a board for the weights, about 38 inches by 32 inches, capable of weighing a ton, on which are delineated two ſcales, one of larger diviſions for the half-hundred weights, and the other of ſmaller diviſions for the pound weights.

Fig. 2. Plan of a half-hundred weight of caſt-iron. A an excavation forming the handle without projecting.

Fig. 3. Elevation of a half-hundred weight. A an excavation forming the handle, with B a hole for lead to adjuſt it.

Fig. 4 and 5. Plans of two half-hundred weights, ſhewing the manner they are placed to fill a ſquare allotted for the amount of one hundred weight.

Fig. 6. End elevation of the pound weights of braſs fitted to the ſcale of one inch to a pound, the part ſcooped out at the ſides being to receive the points of the fingers and thumb to lift them without handles.

The larger weights are placed on their particular ſcale beginning at A on the left, and proceeding to the right, and ſo on with each row. The firſt hundred weight covers the blank ſquare; the ſecond, the ſquare marked 1; the third, that marked 2; and ſo on, reſpectively.

The pound weights are placed on their particular ſcale, beginning at B on the left, and proceeding to the right.

There is no ſcale for the quarter weights, being at moſt only two in number, namely, a half-hundred weight and a quarter-hundred weight, of which the total is evident by mere inſpection, and which may be of any convenient ſhape, and placed conſpicuouſly above the two weights which complete the hundreds. The totals of the hundreds and pounds are indicated by the numbers next to the weights reſpectively on the right hand. Hence it follows that the amounts of the weights on the board in hundreds, quarters, and pounds, are accurately known to the weighers by mere inſpection; and that the bookkeeper has it in his power, with a glance, to diſcover whether the weighers call the proper weight; which is impracticable by the preſent modes of weighing. Boards for weighing ſmaller quantities than a ton might be made on the ſame principle, for weights of the ſame dimenſions, with ſcales adapted to the ſize of the board. It is to be underſtood that the weighing is performed without "ſtriking the weights," which is the common phraſe for lifting all the weights off the board each operation: therefore an appropriate mode, according to ſituation and circumſtances, muſt be adopted to ſupport the board with the weights, while the package weighed is removing from its board to give place to another; when, in ſome inſtances, the largeneſs of the package bulges out the ropes of the board, rendering it neceſſary to raiſe the board with the weights a little higher. In ſome caſes the prop, fig. 7., will anſwer the purpoſe, the pinion being moved by a winch. In other caſes the lever, fig. 8., might be adopted, and, in particular inſtances, the whole beam and ſcales, with the goods and weights, might be raiſed and lowered by the lever, fig. 9., aſſiſted by the wheel and pinion.

The greateſt individual weight, for the purpoſe of being portable, is a half-hundred weight. The common balance is uſed with this weighing apparatus, as it proves to be the beſt kind of balance known; being more true for very ponderous bodies than the ſteelyard, which is ſometimes uſed where great accuracy is not required. When a very light package is to be weighed with a board adapted for a much greater weight, a hook and eye are to be uſed at each of the two cords, ſuſpending the board for the weights at A and C, in order to ſhorten them and prevent the board from leaning to one ſide. Where a chain inſtead of a rope is uſed, one of its links will ſerve as an eye to the hook.

WHEELS acting upon each other are the inſtruments by which the tranſmiſſion of mechanic force from one part of a ſyſtem of machinery to another is commonly and conveniently effected. The due connection of the moving parts is accompliſhed, either by the mutual action of proper formed teeth (ſee the article TEETH in this volume), by ſtraps or endleſs bands, or by the friction of one face of a wheel againſt another. The latter method has, when adopted, been generally in ſmall light works, where the preſſure upon the different parts of the machinery is never conſiderable. Mr. Nicholſon ſaw a drawing of a ſpinning-wheel for children, at a charity ſchool, in which a large horizontal wheel with a ſlip of buff-leather glued on its upper ſurface, near the outer edge, drove 12 ſpindles, at which the ſame number of children ſat. The ſpindles had each a ſmall roller likewiſe faced with leather, and were capable, by an eaſy and inſtantaneous motion, of being thrown into contact with the large wheel at pleaſure. Each child, therefore, could throw her own part of the apparatus into work, or cauſe it to ſtop, as often or as long as ſhe pleaſed. The winding bobbins for yarn at the cotton-mills operate on the ſame ſimple and elegant principle, which poſſeſſes the advantage of drawing the thread with an equal velocity, whatever may be the quantity on the bobbin, and cannot break it. We are not aware that the ſame mode of communication has been adopted in large work, except in a ſaw-mill, by Mr. Taylor, of Southampton. In this the wheels act upon each other by the contact of the end grain of wood inſtead of cogs: the whole makes very little noiſe, and wears very well, it has now been in uſe nearly twenty years. There is, of conſequence, a contrivance to make the wheels bear firm againſt each other, either by wedges at the ſockets, or by levers. This principle and method of tranſmitting mechanic power certainly deſerves every attention; particularly as the cuſtomary mode by means of teeth requires much ſkill and care in the execution; and, after all, wants frequent repairs.

WIND-MILL, as its name imports, is a mill for any purpoſe, which receives its motion from the impulſe of the wind.

The internal ſtructure of wind-mills is, of courſe, much the ſame as thoſe of water-mills: the difference between them lying chiefly in the exterior apparatus, the one to receive the force of the water, the other that of the wind. The external apparatus in a wind-mill conſiſts chiefly of the ſails or vanes, which are commonly four, placed in nearly a vertical poſition, and as they turn giving a rotatory motion to an axis inclining but a little from the horizon. The uſual conſtruction and appearance of the ſails are too well known to need any minute deſcription.

As the direction of the wind is very uncertain, it becomes neceſſary to have ſome contrivance for turning the ſails towards it, in order to receive its force in whatever way it may turn; and for this purpoſe two general methods are in uſe. In the one, the whole machine is ſuſtained upon a moveable arbor or axis, perpendicular to the horizon, which is ſupported by a ſtrong ſtand or foot very firmly fixed in the earth; and thus, by means of a lever, the whole machine may be turned round as occaſion requires. In the other method, only the roof, which is circular, can be turned round by means of a lever and rollers, upon which the circular roof moves. This laſt kind of wind-mill is moſtly built of ſtone, in the form of a round turret, having a large wooden ring on the top of it, above which the roof, which muſt likewiſe be of wood, moves upon rollers, as has been already mentioned. To effect this motion the more eaſily, the wooden ring which lies on the top of the building is furniſhed with a groove, at the bottom of which are placed a number of braſs truckles at certain diſtances, and within the groove is placed another ring, by which the whole roof is ſupported. Beams are connected with the moveable ring, and a rope is faſtened to one of them, which at the lower extremity is fitted to a windlaſs or axis in peritrochio; and this rope being drawn through an iron hook fixed at the ground, and the windlaſs turned round, the ſails and roof will be turned round alſo, in order to catch the wind in any direction. Both theſe methods of conſtruction have their advantages and diſadvantages. The former is the leaſt expenſive, as the whole may be made of wood, and of any form that is thought proper; while the other requires a more coſtly building: and the roof being round, the building muſt alſo be ſo; while the former can be made of any form, but has the inconvenience of being liable to be carried off altogether by a very high wind.

In art. 50, of the introductory part of this volume, we have ſtated the principal reſults of the experiments and reſearches of

Smeaton, relative to the ſhape, poſition, and magnitude of ſails, when *four* is the number adopted. To theſe it might be proper to add here ſome of the remarks which have been made by Parent, Euler, and other philoſophers: but as none of them, except a few by Coulumb, which will be mentioned preſently, appear any way comparable in point of practical utility with thoſe of Smeaton; and as they include, beſides, ſome very intricate inveſtigations; we conceive they may be omitted without any ſerious diſadvantage to the ſtudent. We ſhall now, therefore, proceed to deſcribe a wind-mill, varying in many reſpects from the common conſtruction, invented by Mr. James Verrier, who received a premium from the Society of Arts, for this uſeful ſpecimen of his ingenuity.

This mill, which has 8 quadrangular ſails, is repreſented in fig. 7. pl. XXXVII. where AAA are the three principal poſts, 27 feet $7\frac{1}{2}$ inches long, 22 inches broad at their lower extremities, 18 inches at their upper, and 17 inches thick. The column B is 12 feet $2\frac{1}{2}$ inches long, 19 inches in diameter at its lower extremity, and 16 inches at its upper: it is fixed in the centre of the mill, paſſes through the firſt floor E, having its upper extremity ſecured by the bars GG. EEE are the girders of the firſt floor, one of which only is ſeen, being 8 feet 3 inches long, 11 inches broad, and 9 thick: they are mortiſed into the poſts AAA and the column B, and are about 8 feet 3 inches diſtant from the ground floor. DDD are three poſts, 6 feet 4 inches long, 9 inches broad, and 6 inches thick: they are mortiſed into the girders EF of the firſt and ſecond floor, at the diſtance of 2 feet 4 inches from the poſts A, &c. FFF are the girders of the ſecond floor, 6 feet long, 11 inches broad, and 9 thick: they are mortiſed into the poſts A, &c. and reſt upon the upper extremities of the poſts D, &c. The three bars GGG are 3 feet $1\frac{1}{2}$ inches long, 7 inches broad, and 3 thick: they are mortiſed into the poſts D and the upper end of the column B, 4 feet 3 inches above the floor. P is one of the beams which ſupport the extremities of the bray-trees or brayers: its length is 2 feet 4 inches, its breadth 8 inches, and its thickneſs 6 inches. I is one of the bray-trees into which the extremity of one of the bridge-trees K is mortiſed. Each bray-tree is 4 feet $9\frac{1}{2}$ inches long, $9\frac{1}{2}$ inches broad, and 7 thick; and each bridge-tree is 4 feet 6 inches long, 9 inches broad, and 7 thick, being furniſhed with a piece of braſs on its upper ſurface to receive the under pivot of the mill-ſtones. LL are two iron ſcrew-bolts, which raiſe or depreſs the extremities of the bray-trees. MMM are the three mill-ſtones, and NNN the iron ſpindles or arbors on which the turning mill-ſtones are fixed. O is one of three wheels or trundles which are fixed on the upper ends of the ſpindles NNN: they are 16 inches in diameter, and each is furniſhed with 14 ſtaves. *f* is one of the carriage-rails on which the upper pivot of the ſpindle turns, and is 4 feet 2 inches long, 7 inches broad, and 4 thick. It turns on an iron bolt at one end, and the other end ſlides in a bracket fixed to one of the joiſts, and forms a mortiſe in which a wedge is driven to ſet the rail and trundle in or out of work: *t* is the horizontal ſpur-wheel that impels the trundles; it is 5 feet 6 inches diameter, is fixed to the perpendicular ſhaft T, and is furniſhed with 42 teeth. The perpendicular ſhaft T is 9 feet 1 inch long, and 14 inches in diameter, having an iron ſpindle at each of its extremities: the under ſpindle turns in a braſs block fixed into the higher end of the column B; and the upper ſpindle moves in a braſs plate inſerted into the lower ſurface of the carriage-rail C. The ſpur-wheel *r* is fixed on the upper end of the ſhaft T, and is turned by the crown wheel *v* on the windſhaft *c*; it is 3 feet 2 inches in diameter, and is furniſhed with 15 cogs. The carriage-rail C, which is fixed on the ſliding kerb Z, is 17 feet 2 inches long, 1 foot broad, and 9 inches thick. YYQ is the fixed kerb, 17 feet 3 inches diameter, 14 inches broad, and 10 thick, and is mortiſed into the poſts AAA, and faſtened with ſcrew-bolts. The ſliding kerb Z is of the ſame diameter and breadth as the fixed kerb, but its thickneſs is only 7½ inches. It revolves on 12 friction-rollers fixed on the upper ſurface of the kerb YYQ, and has 4 iron half-ſtaples, Y, Y, &c. faſtened on its outer edge, whoſe perpendicular arms are 10 inches long, 2 inches broad, and 1 inch thick, and embrace the outer edge of the fixed kerb, to prevent the ſliding one from being blown off. The capſills X, V, are 13 feet 9 inches long, 14 inches broad, and 1 foot thick: they are fixed at each end with ſtrong iron ſcrew-bolts to the ſliding kerb, and to the carriage-rail C. On the right hand of *w* is ſeen the extremity of a croſs-rail, which is fixed into the capſills X and V by ſtrong iron bolts: *e* is a bracket 5 feet long, 16 inches broad, and 10 inches thick; it is buſhed with a ſtrong braſs collar, in which the inferior ſpindle of the windſhaft turns, and is fixed to the croſs-rail *w*: *b* is another bracket 7 feet long, 4 feet broad, and 10 inches thick; it is fixed into the fore ends of the capſills, and, in order to embrace the collar of the windſhaft, it is divided into two parts which are fixed together with ſcrew-bolts. The windſhaft *c* is 15 feet long, 2 feet in diameter at the fore end, and 18 inches at the other: its pivot at the back end is 6 inches diameter; and the ſhaft is perforated, to admit an iron rod to paſs eaſily through it. The vertical crown-wheel *v* is 6 feet in diameter, and is furniſhed with 54 cogs which drive the ſpur wheel *r*.

The bolſter *d*, which is 6 feet 3 inches long, 13 inches broad, and half a foot thick, is faſtened into the croſs-rail *w*, directly under the centre of the windſhaft, having a braſs pulley fixed at its fore end. On the upper ſurface of this bolſter is a groove in which the ſliding bolt R moves, having a braſs ſtud at its fore end. This ſliding bolt is not diſtinctly ſeen in the figure, but the round top of the braſs ſtud is viſible below the letter *h*; the iron rod that paſſes through the windſhaft bears againſt this braſs ſtud. The ſliding bolt is 4 feet 9 inches long, 9 inches broad, and $\frac{1}{3}$ of a foot thick. At its fore end is fixed a line which paſſes over the braſs pulley in the bolſter, and appears at *a* with a weight attached to its extremity, ſufficient to make the ſails face the wind that is ſtrong enough for the number of ſtones employed; and when the preſſure of the wind is more than ſufficient, the ſails turn on an edge, and preſs back the ſliding bolt, which prevents them from moving with too great velocity; and as ſoon as the wind abates, the ſails, by the weight *a*, are preſſed up to the wind till its force is ſufficient to give the mill a proper degree of velocity. By this apparatus the wind is regulated and juſtly proportioned to the reſiſtance or work to be performed; an uniformity of motion is alſo obtained, and the mill is leſs liable to be deſtroyed by the rapidity of its motion.

That the reader may underſtand how theſe effects are produced, we have repreſented, in fig. 8., the iron rod, and the arms which bear againſt the vanes: *ah* is the iron rod which paſſes through the windſhaft *c* in fig. 7.; *h* is the extremity which moves in the braſs ſtud that is fixed upon the ſliding bolt; *a i*, *a i*, &c. are the croſs-arms at right angles to *a h*, whoſe extremities *i*, *i*, ſimilarly marked in fig. 7., bear upon the edges of the vanes. The arms *a i* are 6½ feet long, reckoning from the centre *a*, 1 foot broad at the centre, and 5 inches thick; the arms *n*, *n*, &c. that carry the vanes or ſails, are 18½ feet long, their greateſt breadth is 1 foot, and their thickneſs 9 inches, gradually diminiſhing to their extremities, where they are only 3 inches in diameter. The 4 cardinal ſails, *m*, *m*, *m*, *m*, are each 13 feet long, 8 feet broad at their outer ends, and 3 feet at their lower extremities; *p*, *p*, &c. are the four aſſiſtant ſails which have the ſame dimenſions as the cardinal ones, to which they are joined by the line SSSS. The angle of the ſail's inclination when firſt oppoſed to the wind is 45 degrees, and regularly the ſame from end to end.

It is evident from the preceding deſcription of this machine, that the windſhaft *c* moves along with the ſails: the vertical crown-wheel *v* impels the ſpur-wheel *r*, fixed upon the axis T, which carries alſo the ſpur-wheel *t*. This wheel drives the three trundles H, one of which only is ſeen in the figure; which being fixed upon the ſpindles N, &c. communicate motion to the turning mill-ſtones.

That the wind may act with the greateſt efficacy upon the ſails, the windſhaft or principal axis muſt always have the ſame direction as the wind. But as this direction is perpetually changing, ſome apparatus is neceſſary for bringing the windſhaft and ſails into their proper poſition. As both the common methods of adjuſting the windſhaft require human aſſiſtance, it would be very deſirable that the ſame effect ſhould be produced ſolely by the action of the wind. This may be done by fixing a large wooden vane or weathercock at the extremity of a long horizontal arm which lies in the ſame vertical plane with the windſhaft. By this means, when the ſurface of the vane and its diſtance from the centre of motion are ſufficiently great, a very gentle breeze will exert a ſufficient force upon the vane to turn the machinery, and will always bring the ſails and windſhaft to their proper poſition. This weathercock, it is evident, may be applied either to machines which have a moveable roof, or to those which revolve upon a vertical arbor.

Prior to the French revolution, wind-mills were more numerous in Holland and the Netherlands than in any other part of the world, and there they ſeem to have been brought to a very high ſtate of perfection. This is evident not only from the experiments of Mr. Smeaton, from which it appears that ſails weathered in the Dutch manner produced nearly a maximum effect, but alſo from the obſervations of the celebrated Coulomb. This philoſopher examined above fifty wind-mills in the neighbourhood of Liſle, and found that each of them performed nearly the ſame quantity of work when the wind moved with the velocity of 18 or 20 feet per ſecond, though there were ſome trifling differences in the inclination of their windſhafts, and in the diſpoſition of their ſails. From this fact, Coulomb juſtly concluded that the parts of the machine muſt have been ſo diſpoſed as to produce nearly a maximum effect.

In the wind-mills on which Coulomb's experiments were made, the diſtance from the extremity of each ſail to the centre of the windſhaft or principal axis was 33 feet. The ſails were rectangular, and their width was a little more than 6 feet, 5 of which were formed with cloth ſtretched upon a frame, and the remaining foot conſiſted of a very light board. The line which joined the board and the cloth formed, on the ſide which faced the wind, an angle ſenſibly concave at the commencement of the ſail, which diminiſhed gradually till it vaniſhed at its extremity. Though the ſurface of the cloth was curved, it may be regarded as compoſed of right lines perpendicular to the arm or whip which carries the frame, the extremities of theſe lines correſponding with the concave angle formed by the junction of the cloth and the board. Upon this ſuppoſition theſe right lines at the commencement of the ſail, which was diſtant about 6 feet from the centre of the windſhaft, formed an angle of 60 degrees with the axis or windſhaft, and the lines at the extremity of the wing formed an angle increaſing from 78 to 84 degrees, according as the inclination of the axis of rotation to the horizon increaſed from 8 to 15 degrees; or in the millwright's terms, the greateſt *angle of weather* was 30 degrees, and the leaſt varied from 12 to 6 degrees, as the inclination of the windſhaft varied from 8 to 15 degrees. A pretty diſtinct idea of the ſurface of wind-mill ſails may be conveyed by conceiving a number of triangles ſtanding perpendicular to the horizon, in which the angle contained between the hypothenuſe and the baſe is conſtantly diminiſhing; the hypothenuſe of each triangle will then be in the ſuperficies of the vane, and they would form that ſuperficies if their number were infinite.

Mr. Richard Hall Gower, a gentleman in the ſea ſervice of the Eaſt-India Company, made ſome judicious experiments with a view of determining the proper angles of weather which ought to be given to the vanes of a vertical wind-mill: his general concluſion is, that each vane ſhould be a ſpiral, generated by the circular motion of a radius, and of a line moving at right angles to the plane of a circular motion. The conſtruction he deduces from his enquiries is ſimple, being this:

The length, breadth, and angle of weather at the extremity of a vane being given; to determine the angles of weather at different diſtances from the centre.

Let AB, fig. 9., pl. XXXV. be the length of the vane; BC its breadth; and BCD the angle of weather at the extremity of the vane, equal to 20 degrees. With the length of the vane AB, and breadth BC, conſtruct the iſoſceles triangle ABC: from the point B draw BD perpendicular to CB, then BD is the proper depth of the vane.

Divide the line AB into any number of parts (five, for inſtance); at thoſe diviſions draw the lines 1E, 2F, 3G, and 4H, parallel to the line BC; alſo, from the points of diviſion 1, 2, 3, and 4, draw the lines 1I, 2K, 3L, and 4M, perpendicular to 1E, 2F, 3G, &c. all of them equal in length to BD. Join EI, FK, GL, and HM: then the angles 1EI, 2FK, 3GL, and 4HM, are the angles of weather at thoſe diviſions of the vane; and if the triangles be conceived to ſtand perpendicularly to the plane of the paper, the angles I, K, L, M, and D, becoming the vertical angles, the hypothenuſe of theſe triangles will, as before ſuggeſted, give a perfect idea of the weathering of the vane as it recedes from the centre. *Phil. Mag.* No. 14.

Some theoretical remarks on this ſubject are inſerted in vol. i. art. 547.

Mr. John Bywater, of Nottingham, took out a patent in September, 1804, for a method of clothing and unclothing the ſails of windmills *while in motion* (provided they are made after the Dutch manner), by which the mill may be clothed either in whole or in part, in an eaſy and expeditious manner, by a few revolutions of the ſails, whether they are going faſt or ſlow, leaving the ſurface ſmooth, even, and regular in breadth from top to bottom; and in like manner the cloth, or any part of it, may be rolled or folded up to the whip at pleaſure, by ſimple and durable machinery. The invention conſiſts in either folding or unfolding the cloths while the ſails are in motion, by means of cylinders or rollers of any ſhape, as long as the ſails, with a toothed wheel at one end of each, working either directly or indirectly into two wheels without arms, which are hung ſo as to turn upon a ring of iron fixed to the ſhaft-head cloſe behind the back-ſtocks, and which may be alternately ſtopped; ſo that the wheels at the ends of the cylinders muſt directly, or by means of a connection of wheels called carriers or nuts, work into them by revolving round them through the power of the wind acting on the ſails; ſo that the cylinders muſt neceſſarily turn round, and roll up or fold, or unroll or unfold the cloth which is faſtened to them, according to the reſpective wheel without arms, which is ſtopped for that purpoſe. Such is the general contrivance: a detailed account, with figures, may be ſeen in the Repertory of Arts, &c. vol. vi. N. S.

Horizontal WIND-MILLS. A variety of opinions have been entertained reſpecting the relative advantages of horizontal and vertical wind-mills. Mr. Smeaton, with great juſtice, gives a decided preference to the latter; but when he aſſerts that horizontal wind-mills have only $\frac{1}{8}$ or $\frac{1}{10}$ of the power of vertical ones, he certainly forms too low an eſtimate of their power. Mr. Beatſon, on the contrary, who has received a patent for the conſtruction of a new horizontal wind-mill*, ſeems to be prejudiced in their favour, and greatly exaggerates their comparative value. From an impartial inveſtigation, it will probably appear that the truth lies between theſe two oppoſite opinions; but before entering on this diſcuſſion, we muſt firſt conſider the nature and form of horizontal wind-mills.

In fig. 9. of plate XXXVII. CK is the vertical axis or the wind-ſhaft, which moves upon pivots. Four croſs-bars, CA, CD, IB, FG, are fixed to this arbor, which carry the frames APIB, DEFG. The ſails AI, EG, are ſtretched upon theſe frames, and are carried round the axis CK by the perpendicular impulſe of the wind. Upon the axis CK a toothed wheel is fixed, which gives motion to the particular machinery that is employed. In the figure, only two ſails are repreſented; but there are always other two placed at right angles to theſe. Now, let the ſails be expoſed to the wind, and it will be evident that no motion will enſue; for the force of the wind upon the ſail AI is counteracted by an equal and oppoſite force upon the ſail EG. In order, then, that the wind may communicate motion to the machine, the force upon the returning ſail EG muſt either be removed by ſcreening it from the wind, or diminiſhed by making it preſent a leſs ſurface when returning againſt the wind. The firſt of theſe methods is adopted in Tartary, and in ſome provinces of Spain; but is objected to by Mr. Beatſon, from the inconvenience and expence of the machinery and attendance requiſite for turning the ſcreens into their proper poſitions. Notwithſtanding this objection, however, this is probably the beſt method of diminiſhing the action of the wind upon the returning ſails; for the moveable ſcreen may eaſily be made to follow the direction of the wind, and aſſume its proper poſition, by means of a large wooden weathercock, without the aid either of men or machinery. It is true, indeed, that the reſiſtance of the air in the returning ſails is not completely removed; but it is at leaſt as much diminiſhed as it can be by any method hitherto propoſed. Beſides, when this plan is reſorted to, there is no occaſion for any moveable flaps and hinges, which muſt add greatly to the expence of every other method.

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* See Repertory of Arts, &c. vol. ii. pa. 13. N. S.

The mode of bringing the ſails back againſt the wind, which Mr. Beatſon invented, is, perhaps, the ſimpleſt and beſt for that end. He makes each ſail AI to conſiſt of 6 or 8 flaps or vanes, AP *b* 1, *b* 1 *c* 2, &c. moving upon hinges repreſented by the dark lines, AP, *b* 1, *c* 2, &c. ſo that the lower ſide *b* 1 of the firſt flap wraps over the hinge or higher ſide of the ſecond flap, and ſo on. When the wind, therefore, acts upon the ſail AI, each flap will preſs upon the hinge of the one immediately below it, and the whole ſurface of the ſail will be expoſed to its action. But when the ſail AI returns againſt the wind, the flaps will revolve round upon their hinges, and preſent only their edges to the wind, as is repreſented at EG, ſo that the reſiſtance occaſioned by the return of the ſail muſt be greatly diminiſhed, and the motion will be continued by the great ſuperiority of force exerted upon the ſails in the poſition AI.

In computing the force of the wind upon the ſail AI, and the reſiſtance oppoſed to it by the edges of the flaps in EG, Mr. Beatſon finds, that when the preſſure upon the former is 1872 pounds, the reſiſtance oppoſed by the latter is only about 36 pounds, or $\frac{1}{52}$ part of the whole force; but he neglects the action of the wind upon the arms, CA, &c. and the frames which carry the ſails, becauſe they expoſe the ſame ſurface in the poſition AI, as in the poſition EG. This omiſſion, however, has a tendency to miſlead us in the preſent caſe, as we ſhall now ſee; for we ought to compare the whole force exerted upon the arms, as well as the ſail, with the whole reſiſtance which theſe arms and the edges of the flaps oppoſe to the motion of the wind-mill. By inſpecting fig. 9., it will appear, that if the force upon the edges of the flaps, which Mr. Beatſon ſuppoſed to be 12 in number, amounts to 36 pounds, the force ſpent upon the bars CD, DG, GF, FE, &c. cannot be leſs than 60 pounds. Now, ſince theſe bars are acted upon with an equal force, when the ſails have the poſition AI, $1872+60=1932$ will be the force exerted upon the ſail AI and its appendages, while the oppoſite force upon the bars and edges of the flaps when returning againſt the wind will be $36+60=90$ pounds, which is nearly $\frac{1}{20}$ of 1932, inſtead of $\frac{1}{52}$ as computed by Mr. Beatſon. Hence we may ſee the advantages which will probably ariſe from uſing a ſcreen for the returning ſail inſtead of moveable flaps, as it will preſerve not only the ſails, but the arms and the frame which ſupport it, from the action of the wind*.

Mr. Brewſter makes alſo the following remarks on the comparative power of horizontal and vertical wind-mills. It has been already ſtated, that Mr. Smeaton rather under-rated the former while he maintained that they have only $\frac{1}{8}$ or $\frac{1}{10}$ the power of the latter. He obſerves, that when the vanes of a horizontal and a vertical mill are of the ſame dimenſions, the power of the latter is 4 times that of the former, becauſe, in the firſt caſe, only one ſail is acted upon at once, while, in the ſecond caſe, all the four receive the impulſe of the wind. This, however, is not ſtrictly true, ſince the vertical ſails are all oblique to the direction of the wind. Let us ſuppoſe that the area of each ſail is 100 ſquare feet; then the power of the horizontal ſail may be called $100 \times \text{ſin.}^2\, 70^\circ$ (which is the common angle of inclination) = 88 nearly; but ſince there are 4 vertical ſails, the power of them all will be 4 × 88 = 352: ſo that the power of the horizontal ſail is to that of the 4 vertical ones as 1 to 3.52, and not as 1 to 4, according to Mr. Smeaton. But Mr. Smeaton alſo obſerves, that if we conſider the further diſadvantage which ariſes from the difficulty of getting the ſails back againſt the wind, we need not wonder if horizontal wind-mills have only about $\frac{1}{8}$ or $\frac{1}{10}$ of the common ſort. We have already ſeen that the reſiſtance occaſioned by the return of the ſails amounts to $\frac{1}{20}$ of the whole force which they receive; by ſubtracting $\frac{1}{20}$, therefore, from $\frac{1}{352}$, we ſhall find that the power of horizontal wind-mills is only $\frac{1.03}{4.40}$, or little more than $\frac{1}{4}$ leſs than that of vertical ones. This calculation proceeds upon a ſuppoſition that the whole force exerted upon vertical ſails is employed in turning them round the axis of motion; whereas a conſiderable part of this force is loſt in preſſing the pivot of the axis or wind-ſhaft againſt its gudgeon. Mr. Smeaton has overlooked this circumſtance, otherwiſe he could never have maintained that the power of 4 vertical ſails was quadruple the power of one horizontal ſail, the dimenſions of each being the ſame. Taking this circumſtance into the account, we cannot be far wrong in ſaying that, in theory at leaſt, if not in practice, the power of a horizontal wind-mill is about $\frac{1}{3}$ or $\frac{1}{4}$ of the power of a vertical one, when the quantity of ſurface and the form of the ſails are the ſame, and when all the parts of the horizontal ſails have the ſame diſtance from the axis of motion as the correſponding parts of the vertical ſails. But if the horizontal ſails have the poſition AI, EG, in fig. 9, inſtead of the poſition CA *d m*, CD *o n*, their effect will be greatly increaſed, though the quantity of ſurface is the ſame, becauſe the part CP 3 *m* being transferred to BI 3 *d*, has much more power to turn the ſails. Having this method, therefore, of increaſing the effect of horizontal ſails, which cannot be applied to vertical ones, we would encourage every attempt to improve their conſtruction, as not only laudable in itſelf, but calculated to be of eſſential utility in a commercial country. *Brewſter's Ferguſon*, vol. ii. See alſo CONDENSER *of Forces* in this vol.

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* The ſails of horizontal wind-mills are ſometimes fixed like floatboards on the circumference of a large drum or cylinder. Theſe ſails move upon hinges ſo as to ſtand at right angles to the drum, when they are to receive the impulſe of the wind; and when they return againſt it, they fold down upon its circumference. See Repertory of Arts, vol. 6.

An ingenious horizontal mill by Meſſrs. *Claude François* and *Jean Claude du Boſt*, is deſcribed in Recueil des Machines et Inventions approuvées par l'Acad. Roy. des Sciences. tom. vii.

WIPERS, in ſome kinds of machinery, as oil-mills, powder-mills, fulling-mills, are pieces projecting generally from horizontal axles, for the purpoſe of raiſing ſtampers, pounders, or heavy piſtons, in vertical directions, and then leaving them to fall by their own weight.

When the wipers are only ſmall cylinders projecting perpendicularly from the ſurface of the horizontal arbor on which they are fixed, the force with which they elevate the reſpective ſtampers will not act uniformly during the whole time in which they are riſing: yet a uniformity of force and velocity is generally a deſirable thing to be attained, and may always be effected by aſſigning a proper form to the wipers and communicating parts. A few directions for the determination of the due ſhape are here given for the uſe of the mechanic.

Suppoſe that in fig. 15. pl. XXXII. the circle deſcribed about the centre *a* is a vertical ſection of the arbor on which the wipers are placed; and that the line *b a* ſhews the diſtance of an arm of one of the ſtampers from the centre *a*: deſcribe with centre *a* and radius *a b* an arc *b c d* . . . *k*, on which ſet off the equal parts *b c*, *c d*, *d e*, *e f*, &c. as ſmall as can conveniently be done: draw the radii *a c*, *a d*, *a e*, &c. on the extremities of which erect perpendiculars equal to the reſpective arcs *c b*, *d b*, *e b*, &c. and continue them until the laſt of them N *k* is equal to the height to which the ſtamper is to be elevated: this being done, draw the curve N *b* through the extremities of the ſeveral perpendiculars to the radii, it will form an involute of the circular arc *b k* (which indeed may be either conſtructed thus, or in the uſual way at once, with a thread), and will be the figure that may be given to the upper ſurface of a wiper, when it is to give a uniform motion to the riſing ſtamper. For as all the radii of curvature of N *b* are tangents to the circumference of the generating circle *b k*, the arm M *b* of the ſtamper can never touch the wiper in more than one point (or horizontal line, whoſe ſection is a point). When it is the point δ, for example, the radius *a d* which anſwers to the tangent δ *d* will be horizontal; of conſequence δ *d* will be perpendicular to the horizon, and its extremity δ alone will touch M *b*; δ *d* at the ſame time will be the height to which the ſtamper will be raiſed. As the ſame thing will obtain at all the points where the arm M *b* touches the wiper, the arm of the lever which communicates the force will be conſtantly the ſame, that is, it will be equal to *a b*; and the arm of the lever at which the reſiſtance acts being always equal to M *b*, it follows that the ſtampers will be raiſed entirely with a uniform force, and in a direction perpendicular to the horizon.

To determine the poſition of the point *k*, or the magnitude of the arc *k b*, the diſtance *a b* muſt be known, and the circumference *c* of the circle found correſponding to this radius: then make the line L equal to the height to which the ſtamper is to be raiſed; and ſay as C to L, ſo is 360° to the degrees and parts in the arc *b k* or the angle *b a k*: draw from *a* the line *b k*, making with *b a* the angle thus found, and *k* is then aſcertained.

Divide the line L and the arc bk into an *evenly even* number of parts, ſet off from the points c, d, e, &c. of the arc the tangents in arithmetical progreſſion, and equal to the reſpective parts on the line L meaſured from one of its extremities; and thus the curve N δ b will be traced with great facility. The ſhape of the wipers, as they are fixed ſingly in the arbor, will alſo appear from the ſame figure.

In the figure we have repreſented only one ſtamper and one wiper: but it often happens that 6, 8, 10, or more ſtampers are worked by wipers projecting from one horizontal arbor: in this caſe the wipers ſhould be ſo diſtributed that the reſiſtance ariſing from all the ſtampers ſhall be as nearly as poſſible a conſtant quantity: to effect this, let all the ſtampers be placed at equal diſtances in a line parallel to the axle or arbor; let alſo a ſingle ſpiral run once completely round from one end of the arbor to the other, and let the wipers be at equidiſtant poſitions on this ſpiral: then will all the ſtampers be raiſed and permitted to fall at equidiſtant intervals during every rotation of the arbor.

Sometimes a ſmall roller is fixed to the extremity of the arm M b, to diminiſh the friction; and in this caſe a curve muſt be drawn within N b, parallel to it, and at a diſtance equal to the radius of the roller; this new curve exhibiting the ſhape and poſition of the upper face of the wiper.

In ſome machines ſtampers or piſtons are raiſed by giving a proper curvature to the arm M b, and fixing the roller upon the extremity of a bent bar, whoſe end is in the direction of a radius produced: in this caſe the arm muſt be ſhaped into part of a cycloid, the radius of whoſe generating circle is equal to the diſtance from the extremity of the wiper to the centre of the arbor; and this curve muſt be placed at the outer part of the rollers, to form the lower face of the arm.

The wiper may often be formed with great propriety like the Archimedean ſpiral, and thus raiſe a ſtamper with a uniform motion. To this end let AH (fig. 12. pl. XXXII.) be a wheel put into motion by any power which is ſufficient to raiſe the weight MN, by its extremity O, from O to e, in the ſame time that the wheel moves round one fourth of its circumference, it is required to fix upon its rim a wing OBCDEH which ſhall produce this effect with an uniform effort. Divide the quadrant OH into any number of equal parts O m, mn, &c. the more the better, and oe into the ſame number ob, bc, cd, &c. and through the points m, n, p, H draw the indefinite lines AB, AC, AD, AE, and make AB equal to Ab, AC to Ac, AD to Ad, and AE to Ae; then through the points O, B, C, D, E, draw the curve OBCDE, which is a portion of the ſpiral of Archimedes, and will be the proper form for the wiper or wing

OHE. It is evident that when the point *m* has arrived at O, the extremity of the frame will have arrived at *b*, becauſe AB is equal to A *b*; and for the ſame reaſon, when the points *n*, *p*, H, have ſucceſſively arrived at O, the extremity of the frame will have arrived at the correſponding points *c*, *d*, *e*. The motion therefore will be uniform, becauſe the ſpace deſcribed by the weight is proportional to the ſpace deſcribed by the moving power, O *b* being to O *c* as O *m* to O *n*. If it be required to raiſe the weight MN with an accelerated or retarded motion, we have only to divide the line O *e*, according to the law of acceleration or retardation, and divide the curve OBCDE as before. It is ſcarcely neceſſary to add, that the vertical bar between N and M muſt be kept from lateral deviations, by being made either to run between rollers, or to ſlide in a groove.

We have all along ſuppoſed that the wheel or the arbor which carries the wipers turns upon a horizontal axis: we might exhibit methods by which ſtampers, &c. could be raiſed uniformly by wheels moving at right angles to the plane in which theſe ſtampers move; but ſuch methods are intricate and not much to be recommended, as they may always be avoided by a ſmall addition to the machinery, or ſome ſlight modifications in its general diſtribution.

YARN, in general, denotes the manufacture of wool, hemp, flax, cotton, &c. converted into filaments or threads, which are ſubſervient to a variety of uſeful purpoſes.

Formerly all yarn was ſpun or twiſted by means of the diſtaff, or the wheel; but lately, the ingenuity of mechanics, and the powers of machinery, have been called in aid to facilitate that operation. In June, 1787, Meſſrs. *John Kendrew* and *Thomas Porthouſe* obtained a patent for their invention of a machine, upon new principles, deſigned to ſpin yarn from hemp, tow, flax, or wool.—As this privilege is now expired, and ſuch contrivance promiſes to be very uſeful in the woollen as well as other manufactures, we ſhall ſubjoin an account of the conſtruction, as extracted from the ſpecification inſerted in the Repertory of Arts and Manufactures.

This machine may be worked by water, or as a horſe-mill, or in any other way, and is made and uſed in the following manner: There is a cylinder, marked A in the drawing, fig. 1. plate XXXVII., three feet diameter, and ten inches broad, made of dry wood or metal, turned true, and covered on its circumference with a ſmooth leather, upon which are placed the rollers marked D, covered with leathers and ſupported in their ſituations by the ſlits in the covered piece of wood marked K, in which the iron axes of the rollers turn, but ſuffers them to preſs on the wheel marked A. There muſt be another piece ſimilar to the above, to ſupport the other end of the rollers. Theſe rollers are of different weights. The upper roller marked DI is two ſtone, the reſt decreaſing to the laſt, which is only two pounds weight and one half. There is an iron fluted roller, marked F, furniſhed with a toothed wheel at each end, and a wood one, marked G, covered with cloth, and over it a ſmooth leather. There is an aſſiſting roller, marked H, of fluted iron. Theſe rollers are ſupported by their axes, turning in the ſlit, marked 2, of the piece of wood, marked M (fig. 3.), which is here ſeparated from the end of the frame marked 8, to ſhew the rollers and wheelwork. The rollers marked G and F are ſqueezed together by means of the lever marked *p*, and its weight marked *w* (fig. 3.). The roller marked H is preſſed to the mark G by its axis, acting upon the inclined plane marked *x* (fig. 3.). There is a rubbing roller covered with woollen cloth, and on its axis is a ſmall wheel, marked I, driven by the wheel marked S. This roller reſts upon the roller marked G, and by its motion prevents any dirt or fibres from adhering to it. There is a cloth, marked N, revolving over two rollers marked O, O, which has motion given to it from the wheel marked C, by means of another wheel marked P. This cloth moves at the ſame rate as the ſurface of the wheel marked A. There is a ſupporter, marked Y, of the axis of the wheels marked O, P, but is removed, in order to ſhew them; it is fixed by its tenons in the mortiſes marked Z, Z. The roller marked B is kept in action by its endeavour to ſlip down the inclined plane at the top of the piece marked Y, thereby preſſing againſt the revolving cylinder; and another piece, ſimilar to this, muſt be underſtood, to ſupport the other end of the roller's axis. By the ſide of this revolving cloth is a table placed, of the ſame length and breadth as the cloth is, to which belong two ſmooth cloths or leathers, of the ſame ſize as the table. The machine being thus prepared, the attendant or workman muſt take a quantity of hemp, tow, flax, or wool, more or leſs, according to the fineneſs of the thread to be made, and lay or ſpread it evenly upon one of the ſmooth cloths on the table; then place it on the revolving cloth marked N, motion being communicated to the roller marked F by wheel-work, as uſual, from a water, horſe, or other kind of mill, which wheel-work is communicated to the wheel marked Q, on whoſe axis is a nut, which turns the wheel marked C; and thereby the cylinder marked A moves, and with it all the rollers; by which motion the hemp, tow, flax, or wool, is drawn forward. The cloth turns down, but the hemp, tow, flax, or wool, go upon the cylinder marked A, under the roller marked B, and ſo forward under all the rollers marked D, then falls in between the rollers marked G, F, turns under the roller marked

G, and over the roller marked H, which, as it gives the rollers hold of the hemp, tow, flax, or wool, in two places, enables them to draw forward the long fibres thereof, though many of them are to draw from under the marks 4 or 5 of the preſſing-rollers, marked D; it then falls into a canniſter, marked R, and as by the wheel-work the rollers marked F, G, H, move three times faſter than the cloth and cylinder, the ſliver muſt be three times longer than when preſented. By the time this is drawing, the other cloth is filled with hemp, tow, flax, or wool, as before, and laid upon the revolving roller, laying the hemp, tow, flax, or wool, over the end of the other, which goes forward as before, and thus a continued ſliver is produced as long as the machine continues its motion. But in order that this ſliver may come out of the canniſter marked R, without entanglement, it muſt paſs through an inſtrument marked 5 (fig. 3.), placed over the rollers marked F, G, its open ſide marked T, to the cylinder at mark 4, ſupported by its ends marked V, V, in the ſlit marked W, of the before-deſcribed pieces marked K. The aperture X is ſo ſmall as to preſs the fibres cloſe to each other in their paſſage through it previous to their paſſing the rollers, by which means they remain preſſed ſide by ſide in the ſliver, and will not entangle. Theſe thick ſlivers are drawn ſmaller by a ſimilar proceſs, and in the ſame manner is uſed for cotton, but the machines for drawing are all of the ſame ſtructure as the above, except that they have no revolving cloth. The ſliver is applied to the cylinder under the roller marked B which draws it forward under all the rollers, as before deſcribed, drawing it out, or lengthening it, every freſh machine through which it preſſes, till it be ſmall enough for the ſpinning machine. It muſt be remarked, that the cylinders are made leſs in diameter, according to the different ſmallneſs of the ſliver intended to be drawn upon them at the firſt; whilſt the ſliver is at its greateſt thickneſs, the cylinder is required to be three feet diameter, as above deſcribed, the next rather leſs, and ſo on to the laſt, which is only two feet. The aperture of the bottom of the contractor belonging to each machine is alſo made one third part ſmaller than another in ſucceſſion, from the greateſt to the ſmalleſt cylinder; as alſo the drawing rollers marked F, G, H, are furtheſt from the preſſing-roller marked D in the longeſt cylinder, and neareſt at the ſmaller cylinder. At the largeſt cylinder the diſtance is about nine inches, and the ſmalleſt about four inches; but their diſtance cannot in all caſes be fixed, as it depends on the different length of the ſlivers of the hemp, tow, flax, or wool; long ones requiring the diſtances mentioned, and ſhort ones requiring the diſtances much ſhorter than is here ſpecified.

The following ſeveral letters or marks are in the machine figured 2. The ſpinning machine, as to its drawing principle, is the ſame as the drawing machine. The ſlivers are preſented to it in canniſters marked A, and drawn over a cylinder marked B, covered with rollers marked D. The fibres which are to form the thread are drawn from the cylinder by the rollers marked C, the under roller of which is made of fluted iron, the other of wood, covered with leather; they move ſix or eight times faſter than the cylinder marked B; are enabled to draw the hemp, tow, flax, or wool, forward from under the preſſing-rollers marked D, by being ſqueezed together with the weights and crooks marked *a*, *a*, locked to the ſmall part of the rollers marked C. There is a belt of ſmooth cloth, marked E, moving on two rollers, which are turned by the wheel marked F, on the axis of the fluted roller; at the oppoſite end of which, as at the mark G, is a nut, which turns the wheel marked H, on whoſe axis is another nut, turning the wheel marked I, and thereby the cylinder marked B, with all its rollers. Theſe rollers move in curved pieces of wooden metal, marked K, which, to prevent confuſion, are not repreſented in their places: they have ſlits in them, in which the rollers' axes are guided, but ſo deep as at all times to ſuffer the rollers to preſs upon the cylinder. Theſe rollers are covered with cloth and leather. The top roller is about ten pounds weight, decreaſing to the ſixth roller, which is only about one pound weight: the yarn is turned by the ſpindles marked L, and rubbed over the wet cloth belt if ſpinning linen yarn, but if ſpinning worſted yarn the belt muſt be removed, that it may not touch it as it paſſes to the ſpool, which it coils round as faſt as the rollers let it out. The ſpindles marked L, are turned by a bolt from the wheel marked M, which derives its motion from the mill, and by a wheel on its axis communicates it to the roller under the mark C by the wheel marked F, and ſo to the reſt, as above deſcribed. The hemp, tow, flax, or wool, is twined in the ſame manner as cotton is by mills.

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ERRATA.

Page	Line
15,	17 *from bottom*, *for* o *read* O.
17,	9, *for* magnitude *read* magnitudes.
22,	17 and 19 *from bottom*, *for* $P r$ *read* $P r'$.
23,	16, *for* into *read* in.
24,	9 *from bottom*, *for* $C' = \frac{P d'}{\cos. a''}$, *read* $C'' = \frac{P d''}{\cos. a''}$.
27,	14 *from bottom*, *for* $\sin. r = \frac{}{R}$ *read* $\sin. r = \frac{y}{R}$.
57,	18 *from bottom*, *for* HG, IG, *read* HG'' IG''',
66,	4 *from bottom*, *for* 112 *read* 119.
93,	4 *from bottom*, *for* he angle *read* of the angle.
119,	15, *for* angle o *read* angle O.
135,	9 *from bottom*, *for* $z \dot{x}$ *read* $\dot{z} \dot{x}$.
136,	2 *from bottom*, $\sqrt{X^2 + Y^2}$ *read* $\sqrt{\dot{X}^2 + \dot{Y}^2}$.
173,	24, *for* has *read* have.
181,	8 *from bottom for* t *read* $\dot{t}$.
188,	12 *from bottom*, *for* 230 *read* 228.
207,	14, *for* fig. 6 *read* fig. 5.
226,	8, *for* P *read* O.
254,	20, *for* fig. 4 *read* fig. 14.
294,	11, *for* a work *read* in a work.
324,	*bottom line*, *for* $W \sin. \dot{E}$ *read* $W \sin. E$.

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